Section 5.0 Case Studies

The Western Coal Mining Work Group (WCMWG) submitted data and information for five case studies demonstrating that computer models can be used to 1) predict mine site hydrology and sedimentology and 2) design and select alternative sediment controls to control hydrology and sedimentology at coal mine sites in the arid/semiarid western coal mining region. The data and information submitted by WCMWG are summarized in the following five case studies.

- Case Study 1 - Compares the performance, cost, and benefits of a model mine located in the *Desert Southwest* region using sedimentation pond systems versus alternate sediment control measures;

- Case Study 2 - Is a follow-up study to Case Study 1 comparing the performance, cost, and benefits of model mines located in the *Intermountain* and *Northern Plains* regions using sedimentation pond systems versus alternate sediment control measures;

- Case Study 3 - Contains surface water runoff modeling and performance-cost-benefit information supporting the addition of lands affected by certain pre-mining activities.

- Case Study 4 - Demonstrates that since 1984, the Jim Bridger Mine, located in southwestern Wyoming, has successfully used alternate sediment control measures, in addition to several sedimentation ponds, to treat disturbed area runoff to prevent degradation of local stream water quality.

- Case Study 5 - The study evaluated available computer models for prediction of watershed runoff and sediment yield for selection of a model that best represents these processes at mine sites in semiarid regions.

5.1 Case Study 1 (Western Coal Mining Work Group, 1999c)

The National Mining Association (NMA), as part of the WCMWG, conducted studies comparing the performance, costs, and benefits of model mines located in the *Desert Southwest* (Case Study 1), *Intermountain* (Case Study 2), and *Northern Plains* (Case Study 2) coal regions. The studies compared results under conditions designed to meet numeric limits with conditions designed for use of alternative sediment control to maintain background sediment yield (WCMWG, 1999c). This section discusses the results of NMA's *Desert Southwest* model mine study.

A representative model mine located in the arid/semiarid southwestern United States was developed for the comparison, including contour maps and corresponding hydrologic and soil databases typical of desert southwest mines. Original and approximate topography were used to model surface drainage, sediment yield, and soil loss rates from the affected watersheds. Results from RUSLE and SEDCAD modeling were generated for the following three scenarios:

1) Pre-mining Undisturbed Watershed - Modeling of the area prior to any surface preparation, surface disturbance, or mining activities was conducted to characterize background water quality, soil loss rates, and sediment yield. Data were used to establish background standards for BMP system control;

2) Post-mining Reclaimed: Numeric Limitations - A sedimentation pond-focused treatment system was modeled that meets 0.5 ml/L settleable solids (SS) at the perimeter outfalls.

3) Post-mining Reclaimed: Sediment Control BMPs - A BMP system focusing on the use of alternate sediment controls was modeled to provide erosion and sediment control for reclaimed lands seeking to approximate undisturbed

background surface drainage volumes and peaks, total settleable solids (TSS) and SS concentrations, soil loss rates, and sediment yields.

Characteristics of the representative model mine area and information used to perform performance and cost evaluations are presented in Table 5a.

Table 5a: Representative Mine Characteristics and Model Input Information

Parameter	Input information
Total Acres	1,188
Actual Disturbed Acres	381.8
Affected Acres	616.7
Unaffected Acres	571.3
Storm Event	10 year – 24 hour
Rainfall	1.8 inches
Soil Type	Sandy clay loam, Loamy sand
Sediment Control BMPs	Manipulation of topography, gradient bench terraces, terrace drains, contour furrows, reclaimed channels, diversion ditches, establishment of permanent vegetation, mulching and detention basins.
Number of Sedimentation Ponds	3, in series
Types of Surface Conditions	Undisturbed; Spoil, backfilled and graded, topdressed, straw mulched and seeded; Revegetated, 1-3 years Revegetated, 4-8 years
Computer Model Input Information (RUSLE)	Rainfall amount, intensity, frequency and duration; soil moisture conditions, soil types, susceptibility to erosion, eroded particle size distributions, infiltration rates, and soil permeability; vegetative ground cover and evapotranspiration rates

The non-process area within the representative model mine contained the following surface conditions: areas containing spoil outslopes and rough and final backfilling and grading; areas where soil resources are being replaced (including topdressing, contour furrowing, mulching, and seeding); and areas with 1-3 years of vegetative growth, or with 4-8 years of more permanent growth.

Non-process area surface conditions also included a final pit undergoing reclamation with the potential for non-process mine drainage to run off the site. This configuration normally represents peak sediment yield potential for a reclaimed area during the mining and reclamation processes. The non-process area was positioned within a portion of the watershed, so that drainage from both the non-process area and the adjacent undisturbed lands were considered in choosing and developing sediment control strategies.

The alternate sediment control BMPs used during reclamation were:

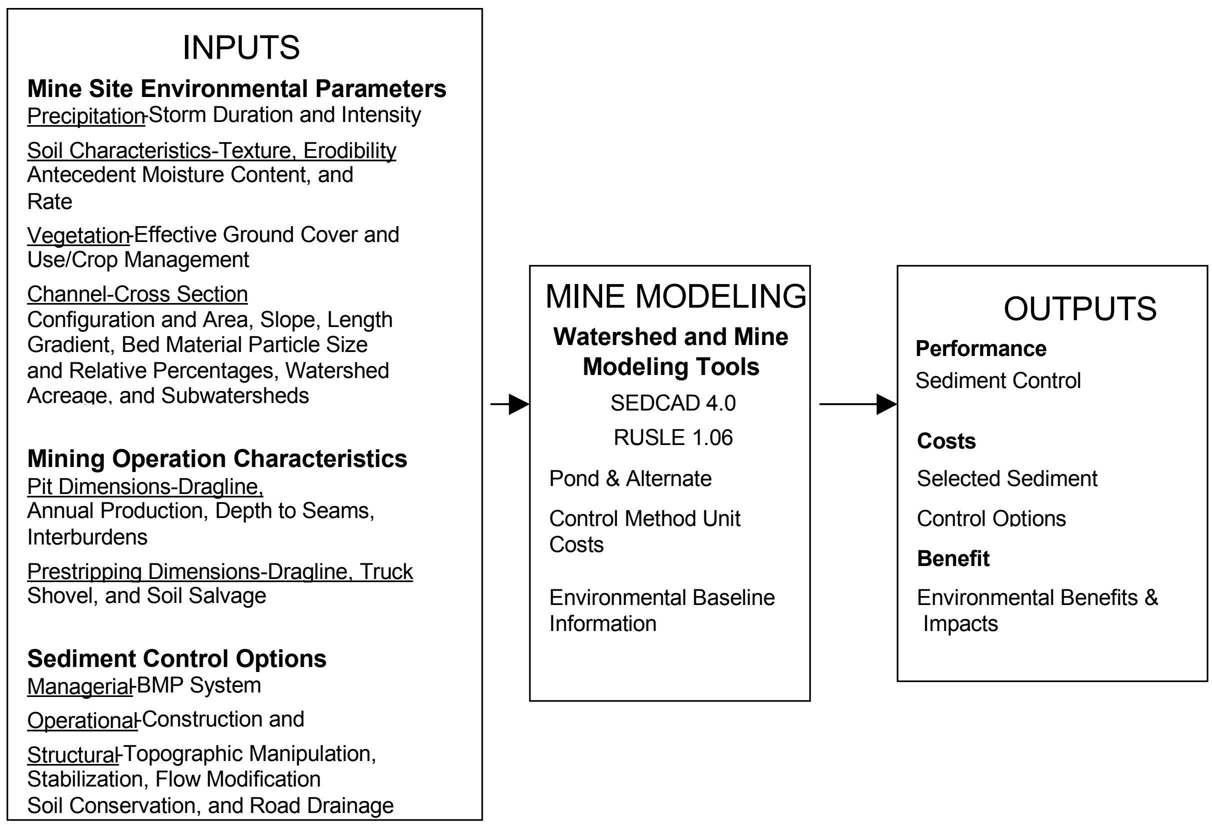
- Manipulation of topography to develop more stable slopes
- Earthen terraces and berms
- Terrace drains
- Contour furrows
- Diversion ditches
- Surface roughening/land imprinting
- Sediment detention basins
- Revegetation

Reclaimed area topography and the extent of area disturbance were held constant in modeling both reclamation sediment control scenarios. Holding these inputs constant enabled and facilitated the analysis and comparison of model results for soil loss, surface drainage rates, surface drainage volumes, and BMP performance.

5.1.1 Modeling Results

The modeling approach used for this study is shown in Figure 5a. The RUSLE 1.06 and SEDCAD 4.0 models were used to estimate values that characterize site hydrology and sedimentology.

Figure 5a: Mine Model Approach: A Method for Evaluating Erosion and Sediment



Control Options (WCMWG, 1999c)

5.1.1.1 RUSLE 1.06

Annual average soil loss was predicted for two scenarios with the help of RUSLE version 1.06. The two scenarios were for pre-mining (undisturbed) conditions and for post-mining (reclaimed with BMPs). The type of input information for the modeling effort is listed in Table

5b. Information input values were based on vegetation, soils, and surface configurations obtained from case study mines and mine permits. Representative data were entered into the RUSLE program to generate sediment loss values. RUSLE input and output data are presented in Appendix D, Tables D-1 through D-5.

For pre-mining, undisturbed conditions, the predicted, weighted average annual soil loss was 4.7 tons/acre/yr. According to the WCMWG, this is a reasonable value for the arid and semiarid coal regions (WCMWG, 1999c). The weighted average annual soil loss of the reclaimed mine lands was 3.0 tons/acre/yr. Data supporting the weighted average soil loss estimates are presented in Appendix D, Table D-6. The soil loss is slightly lower after reclamation because the BMPs allow for improved infiltration and retention of storm water, and for the growth and establishment of vegetation. Also, implementation of BMPs results in landforms that have been reconstructed to facilitate lower erosion rates and enhanced deposition at down-gradient slope boundaries.

5.1.1.2 SEDCAD 4.0

All sediment and hydrology model results from the mine prior to mining and from the mine after reclamation using BMPs to control sediment are similar, whereas the model results for the area reclaimed to meet numeric effluent limitations (0.5 ml/L SS) are considerably lower than the pre-mining conditions. The decrease in sediment yield and runoff resulting from compliance with this limit is expected due to the implementation of sedimentation ponds that impound runoff. To avoid potential adverse impacts on the hydrologic and sediment balance, and to maintain the stability of the fluvial system, drainage from the non-process areas should be as similar to pre-mining drainage as possible. Based on this standard, implementation of BMPs would be a preferred option. Sediment loss, soil loss, and surface runoff model results for undisturbed conditions, non-process areas with sedimentation ponds, and non-process areas with alternative sediment control BMPs are presented in Table 5b. SEDCAD output for each of the three scenarios is presented in Appendix D.

5.1.2 Cost

The WCMWG completed an extensive analysis of costs associated with meeting effluent limitations using sedimentation ponds and implementing BMPs under a Western Alkaline Coal Mining subcategory. Cost estimating criteria for sedimentation ponds and BMPs implemented at the model mine were collected from approved mine permit applications, developed from mine records, and estimated using technical resources and industry experience. These unit cost data are presented in detail in NMA's Mine Modeling Report (WCMWG, 1999c).

The model cost assessment was based on capital costs (design, construction, and removal) and operating costs (inspection, maintenance, and operation) associated with BMPs used over the anticipated bonding periods. The bond release period for meeting numeric effluent standards in the arid and semiarid western coal region can be expected to be ten years or longer (WCMWG, 1999a; Peterson, 1995). With the implementation of alternative sediment control BMPs, reclaimed areas may be eligible for Phase II bond release about five years after they have been successfully revegetated (WCMWG, 1999a).

Capital and operating reclamation costs, as estimated by the WCMWG, for both the effluent numeric limitation and the proposed non-numeric option are presented in Table 5c. The present value of the reclamation costs over the ten year period (discounting at seven percent) is $1,700,000 for the existing guideline and $1,028,000 for the proposed subcategory, or a present value total savings of $672,000 over ten years. This represents a 39 percent overall reduction in costs or $1,764 in savings per disturbed acre. The annualized savings is $95,000 (annualized at seven percent) or $251 annualized savings per acre for the 381 reclaimed acres.

Table 5b: Comparison of Hydrology and Sedimentology Results (modified from WCMWG, 1999c)

	Pre-Mining Undisturbed Conditions	Reclaimed to Meet Numeric Limitations[1,2]		Reclaimed Under Alternate Sediment Control Measures[3]	
	Result	Result	% Change from Pre-mining	Result	% Change from Pre-mining
RUSLE (V 1.06) Modeling Results					
Soil Loss (tons/acre/year) (Weighted Average)	4.7	NM[4]	N/A	3.0	-36
SEDCAD (V 4.0) Modeling Results					
Peak Discharge (cfs) (10 year, 24-hour storm event)	679.09	44.79	-93	601.89	-11
Total Runoff Volume (acre-feet) (10 year, 24-hour storm event)	80.01	48.83	-39	72.93	-9
Sediment (tons) (10 year, 24-hour storm event)	7,004.2	666.1	-90	5,611.1	-20
Sediment (tons/acre) (10 year, 24-hour storm event)	5.9	0.6	-90	4.7	-20
Peak Sediment (mg/L) (10 year, 24-hour storm event)	155,091	28,235	-82	114,800	-26
Peak Settleable Solids (ml/L) (10 year, 24-hour storm)	38.22	0.00	-100	25.86	-32
Settleable Solids (ml/L) (24-hr Volume Weighted) (10 year, 24-hour storm)	17.89	0.00	-100	13.96	-22
Sediment Yield (acre-feet/year) (Average Annual)	8.3	0[5]	-100	6.7	-19

[1] Sediment was controlled with sedimentation ponds.
[2] Assumes ponds are filled to design storage capacity with 3 years of sediment runoff.
[3] Sediment was controlled by alternative sediment control BMPs.
[4] Not measured.
[5] Assumes no sediment is stored in the ponds, and 3 years of annual sediment runoff volume is available. SEDCAD 4.0 uses a subroutine that implements a method similar to RUSLE to determine average annual sediment yield. SEDCAD sedimentology input values were taken directly from the RUSLE version 1.06 analysis.

Table 5c: Cost of Compliance with Numeric Limitations vs. Cost to Implement Alternative Sediment Control BMPs (adapted and revised from WCMWG, 1999c)

Year	Numeric Effluent Limits				Alternate Sediment Control BMPs			
	Capital	Operating	Total	Present Value[1]	Capital	Operating	Total	Present Value[1]
1	$975,435	$15,384	$990,819	$990,819	$760,816	$3,300	$764,116	$764,116
2	2,720	142,804	145,524	136,004	43,577	103,368	146,944	137,332
3	0	190,181	190,181	166,112	0	59,876	59,876	52,298
4	0	88,956	88,956	72,615	0	77,895	77,895	63,586
5	0	26,231	26,231	20,011	0	14,147	14,147	10,793
6	0	161,999	161,999	115,503	-	-	-	-
7	0	15,269	15,269	10,175	-	-	-	-
8	0	15,269	15,269	9,509	-	-	-	-
9	0	133,377	133,377	77,626	-	-	-	-
10	171,607	15,269	186,876	101,648	-	-	-	-
Total (not discounted)	$1,149,761	$804,739	$1,954,501	$1,700,021	$804,393	$258,586	$1,062,979	$1,028,124
Annualized @ 7% over 10 years				$242,045				$146,382

Annualized Savings	$95,663	Present Value Total Savings	$671,897
Annualized Savings per Reclamation Acre[2]	$251	Present Value Total Savings per Acre[2]	$1,764

Costs expressed in 1998 Dollars
[1] Discount Rate: 0.07
[2] Based on 381 disturbed acres

5.2 Case Study 2 (Western Coal Mining Work Group, 2000a)

To complement the results of the model mine study presented in Section 5.1 (Case Study 1), NMA also conducted this follow-up study comparing the performance, cost, and benefits of model mines located in both the *Intermountain* and *Northern Plains* coal regions to meet numeric effluent limitations versus the use of alternative sediment control BMPs (WCMWG, 2000a).

Two models were developed using representative non-process areas within the *Intermountain* and *Northern Plains* regions in the western United States. These models were based on site-specific hydrology and soil databases for the *Intermountain* and *Northern Plains* coal regions. Site-specific input variables include

- Rainfall amount
- Rainfall intensity
- Rainfall frequency
- Rainfall duration
- Antecedent soil conditions
- Soil types
- Susceptibility to erosion
- Eroded particle size distribution
- Infiltration rates
- Soil permeability
- Vegetative ground cover

Other variables such as topography, disturbance area (disturbance footprint), and non-process areas (e.g., backfilling and grading area, surface roughening area, revegetation area, etc.) were standardized and held constant to aid in the comparison of the case studies from the different regions.

For both the *Intermountain* and *Northern Plains* examples, modeling was performed for three scenarios:

1) Pre-mining background - A characterization prior to surface disturbance by mining and reclamation activities that is used to establish site-specific sediment control standards for the proposed BMP treatment system;

2) Numeric Limitation Requirements - Modeling and design of a sediment control system that meets numeric limitations for runoff from non-process areas; and

3) Sediment Control BMPs - Modeling and design of a BMP alternate sediment control system that meets background levels for runoff from non-process areas.

Modeling prior to surface disturbance by mining was conducted to characterize pre-mining background water quality, soil loss rates, and sediment yield. The modeled values serve as a benchmark, establishing standards for the sediment control measures.

Non-process areas also were modeled to meet numeric limitations using typical surface water runoff control and treatment methods for the model's standardized disturbance footprint for both *Intermountain* and *Northern Plains* environmental conditions. Typical surface water runoff treatment systems (sedimentation ponds) were designed to meet the discharge requirements for numeric limitations for surface water runoff (0.5 ml/L settleable solids).

A third modeling scenario using the standardized disturbance footprint was used to meet background sediment yields. This scenario emphasized implementation of an alternate erosion and sediment control system to meet pre-mining watershed runoff conditions and prevent the contribution of additional sediment to the receiving stream.

5.2.1 Modeling Results

Average annual erosion quantities were predicted based on the RUSLE model version 1.06. Input parameter values for the modeling effort were based on vegetation, soils, and surface configurations obtained from existing case study mines and mine permits. RUSLE variables were input to SEDCAD 4.0 to model watershed sedimentology. Since the analysis of a 10-year, 24-hour design storm is typically required, all three scenarios were assessed using the design storm in the SEDCAD 4.0 model. Modeling erosion and sediment controls for non-process areas under numeric and non-numeric (sediment control BMPs) requirements produced the hydrology and sedimentology data for the *Intermountain* and *Northern Plains* non-process areas as shown in Tables 5d and 5e, respectively.

For the *Intermountain* reclaimed area, the sediment control BMPs reduced peak discharge by approximately 38% below background levels, while the treatment designed to meet numeric limitations reduced the peak discharge by 96% below background levels. For the *Northern Plains* reclaimed area, the BMP system reduced peak discharge by approximately 33% below background levels, while the treatment to meet numeric limitations reduced the peak discharge 97% below background levels. For both areas modeled, the sediment control system mimics the background peak discharge levels more closely.

Table 5d: Comparison of Hydrology and Sedimentology Results for the Intermountain Reclamation Model (Western Coal Mining Work Group, 2000a)

	Pre-mining Undisturbed Conditions	Reclaimed to Meet Numeric Limitations		Reclaimed Under Alternate Sediment Control Procedures	
	Result	Result	% Change from Pre-mining	Result	% Change from Pre-mining
Intermountain Non-process Area					
Sediment Production (tons)	1,030	0[1]	-100	660	-36
Peak Discharge (cfs) (10 year, 24-hr storm event)	160	6[2]	-96	100	-38
Total Runoff Volume (acre-ft) (10 year, 24-hr storm event)	27	22[3]	-19	21	-22
Settleable Solids (ml/L) (24-hr Volume Weighted) (10 year, 24-hr storm event)	18	0	-100	15	-17
Peak Settleable Solids (ml/L)	58	0[4]	-100	48	-17
Peak Sediment (mg/L) (10 year, 24-hr storm event)	100,800	0[5]	-100	82,400	-18

[1]Most sediment is trapped in the sediment pond. Minimum amount of sediment released during discharge.
[2]Assumes 100% of runoff volume is discharged from pond over a 2-day period.
[3]Assumes 100% of runoff volume is treated and discharged. This is conservative as some water will be lost to infiltration, minimum pool ponding, and evaporation.
[4]Containment in pond with slow discharge rate will remove all settleable solids.
[5]Containment in pond with slow discharge rate will remove most suspended sediment.

For the *Intermountain* reclaimed area, the proposed sediment control system achieved peak sediment concentrations that were approximately 18% lower than pre-mining background levels, while the treatment designed to meet numeric limitations had peak sediment concentrations that were near zero. This is a direct result of capturing almost 100% of the sediment in sedimentation ponds. The BMP treatment system also achieved superior results in the *Northern Plains* example, with peak sediment concentrations that were approximately 14% lower than pre-mining background levels, while the current subcategory treatment system again had peak sediment concentrations that were near zero.

Table 5e: Comparison of Hydrology and Sedimentology Results for the Northern Plains Reclamation Model (Western Coal Mining Work Group, 2000a)

	Pre-mining Undisturbed Conditions	Reclaimed to Meet Numeric Limitations		Reclaimed Under Alternate Sediment Control Procedures	
	Result	Result	% Change from Pre-mining	Result	% Change from Pre-mining
Intermountain Non-process Area					
Sediment Production (tons)	850	0[1]	-100	520	-39
Peak Discharge (cfs) (10 year, 24-hr storm event)	250	8[2]	-97	167	-33
Total Runoff Volume (acre-ft) (10 year, 24-hr storm event)	42	31[3]	-26	30	-29
Settleable Solids (ml/L) (24-hr Volume Weighted) (10 year, 24-hr storm event)	10	0	-100	8	-13
Peak Settleable Solids (ml/L)	30	0[4]	-100	26	-13
Peak Sediment (mg/L) (10 year, 24-hr storm event)	52,500	0[5]	-100	45,100	-14

[1]Most sediment is trapped in the sediment pond. Minimum amount of sediment released during discharge.
[2]Assumes 100% of runoff volume is discharged from pond over a 2-day period.
[3]Assumes 100% of runoff volume into pond is treated and discharged. This is conservative as some water will be lost to infiltration, minimum pool ponding, and evaporation.
[4]Containment in pond with slow discharge rate will remove all settleable solids.
[5]Containment in pond with slow discharge rate will remove most suspended sediment.

In the *Intermountain* example, sediment yield resulting from the BMP treatment system more closely approximated background at 660 tons (a reduction of 370 tons from background) versus the treatment to meet numeric limits which resulted in a sediment yield of 0 tons (a reduction of 1,030 tons from background). In the *Northern Plains* example, sediment delivery resulting from the BMP system more closely approximated background at 520 tons (a reduction of 330 tons from background) versus treatment to numeric limits that resulted in a yield of 0 tons (a reduction of 850 tons). Settleable solids were released from the *Intermountain* BMP system at a concentration of 48 ml/L (17% below background levels), while treatment to numeric limits reduced SS by almost 100%. For the *Northern Plains* example, SS were released from the BMP treatment system at a concentration of 26 ml/L (13% below background levels), while treatment to numeric limits reduced SS by almost 100%. These results demonstrate that BMP treatment systems are capable of and better suited to release runoff that more closely approximates pre-mining watershed conditions. Using BMP sediment control systems to treat runoff from non-process areas can be expected to significantly improve protection of hydrologic and fluvial balances in watersheds affected by mining in western arid and semiarid alkaline environments.

5.2.2 Costs

Detailed capital and operating costs associated with the sediment control options specified for both the *Intermountain* and *Northern Plains* model mines were developed for 1) meeting numeric limitations, and 2) implementing sediment control measures to mimic background conditions. As was done for the *Desert Southwest* model in Case Study 1, capital costs include design, construction, and removal activities. Operating costs include inspection, maintenance, and operating activities. The costs were developed for anticipated bonding periods of five years and ten years. Design criteria used as the basis of costs for both the *Intermountain* and *Northern Plains* models are summarized in Table 5f.

Table 5f- Model Mine Design Criteria

Sediment Control Technology	Northern Plains Model Mine				InterMountain Model Mine				Comments
	Numeric Limits		Alternate Sediment Control		Numeric Limits		Alternate Sediment Control		
	Quantity	Unit	Quantity	Unit	Quantity	Unit	Quantity	Unit	
Sedimentation Pond (n=1)	31	ac-ft	-	-	22	ac-ft	-	-	
Spillway for Sedimentation	200	linear feet	-	-	175	linear feet	-	-	2:1 side slopes with 50-ft bottom width; Allowed 1.5 ft for rip rap depth, 1 ft freeboard, depth Intermountain=1.35, Northern Plains=1.53
Small Depressions (n=3)	-	-	<1	ac-ft	-	-	<1	ac-ft	
Gradient Bench Terraces	27,637	linear feet	27,637	linear feet	27,637	linear feet	27,637	linear feet	Intermountain=1.8, Northern Plains=2-ft depth with 3:1 and 10:1 cut and fill slopes, 25% of land requires terracing @ 150 ft intervals.
Terrace Drains	8,298	linear feet	8,298	linear feet	8,298	linear feet	8,298	linear feet	Cross-section is V-shaped 2.5' depth; side slopes 3h:1v; 1.5 ft excavation depth for riprap liner, 8-ft bottom width
Channel Stabilization Rip Rap	400	linear feet	-	-	400	linear feet	-	-	Used to stabilize reconstructed drainage channel when sediment pond is removed Yr 10, 8 structures 50-ft in length will be placed at intervals for channel gradient and X-section control, 3:1 side slopes, channel depth = 4.5 ft.
Diversion Channel #1	3,600	linear feet	3,600	linear feet	3,600	linear feet	3,600	linear feet	Trapezoidal X-Section, 8 ft bottom, 3:1 side slope, Northern Plains 2.4ft deep, Intermountain= 2.0 ft deep
Diversion Channel #2	3,650	linear feet	3,650	linear feet	3,650	linear feet	3,650	linear feet	Trapezoidal X-Section, 8 ft bottom, 3:1 side slope, Northern Plains 2.4ft deep, Intermountain= 2.0 ft deep
Diversion Channel #3	880	linear feet	880	linear feet	880	linear feet	880	linear feet	Trapezoidal X-Section, 8 ft bottom, 3:1 side slope, Northern Plains 2.4ft deep, Intermountain= 2.0 ft deep
Revegetation	393.0	Acres	381.2	Acres	392.4	Acres	381.2	Acres	Includes seedbed preparations, seeding, mulching and fertilizing
Surface Roughening	393.0	Acres	381.2	Acres	392.4	Acres	381.2	Acres	Including ripping, contour furrows and land imprinting

The sediment control structures and BMPs used for the *Intermountain* and *Northern Plains* models are as follows:

- Models designed to meet numeric limitations use a single sedimentation pond. Runoff from undisturbed conditions entering the main drainage in the vicinity of the sedimentation pond is conveyed around each side of the pond using grass lined diversions. Some mulching and limited surface roughening has been applied. The reclaimed land surface has been recontoured with terraces to reduce slope lengths and steepness. The reclaimed area for both *Intermountain* and *Northern Plains* scenarios is approximately 381.2 acres, with additional acres of disturbance for the sedimentation pond and diversions of 11.2 acres in the *Intermountain* scenario and 11.8 acres in the *Northern Plains* scenario.

- Models designed to approximate or improve background conditions use a BMP system instead of a sedimentation pond to treat surface runoff. The BMP system includes the same surface topography manipulation as applied to meet numeric limitations, including terraces and recontouring to reduce slope lengths and steepness. No diversions or sedimentation ponds were used. More extensive mulching and surface roughening were applied, including deeper contour furrows, land imprinting and the use of surface depressions. Since these practices typically result in better water harvesting and a subsequent increase in vegetation density, credit was taken for the vegetation density increase on older reclaimed areas.

Capital and operating reclamation costs for meeting numeric limitations and for implementing alternative sediment control measures for the *Intermountain* model mine are presented in Table 5g (WCMWG, 2001). The present values of the total reclamation costs over the ten year period (discounting at seven percent) are $844,132 to meet numeric limitations and $645,266 to implement alternative sediment control measures. This represents a present value total savings of $198,866 over ten years, a 24 percent overall reduction in costs or $522 in savings per disturbed acre when alternate sediment control measures are used. The annualized savings is $28,315 (annualized at seven percent) or $74 annualized savings per acre for the 381 reclaimed acres.

Capital and operating reclamation costs for meeting numeric limits and for implementing alternative sediment control measures for the *Northern Plains* mine model are presented in Table 5h. The present values of the total reclamation costs over the ten year period (discounting at seven percent) are $889,011 to meet numeric limitations and $653,636 to implement alternative sediment control measures. This represents a present value total savings of $235,375 over ten years, a 26 percent overall reduction in costs or $618 in savings per disturbed acre when alternate sediment control measures are used. The annualized savings is $33,512 (annualized at seven percent) or $88 annualized savings per acre for the 381 reclaimed acres.

Table 5g: Cost of Meeting Numeric Limits vs. Cost to Implement Alternative Sediment Control BMPs for the Intermountain Model Mine (adapted and revised from WCMWG, 2001)

Year	Numeric Limitations				Alternate Sediment Controls Measures			
	Capital	Operating	Total	Present Value[1]	Capital	Operating	Total	Present Value[1]
1	$479,458	$10,777	$490,235	$490,235	$428,315	$3,677	$431,992	$431,992
2	43,577	65,142	108,718	101,606	43,577	58,065	101,642	94,993
3	0	36,230	36,230	31,645	0	29,142	29,142	25,454
4	0	67,818	67,818	55,360	0	60,808	60,808	49,638
5	0	45,677	45,677	34,847	53,049	3,563	56,612	43,189
6	0	41,310	41,310	29,453	-	-	-	-
7	0	10,663	10,663	7,106	-	-	-	-
8	0	10,663	10,663	6,641	-	-	-	-
9	0	11,698	11,698	6,808	-	-	-	-
10	134,550	13,319	147,869	80,431	-	-	-	-
Total (not discounted)	$657,585	$ 313,296	$970,881	$844,132	$524,940	$155,255	$680,195	$645,266
Annualized @ 7% over 10 years				$120,186				$91,871

Annualized Savings	$28,315	Present Value Total Savings	$198,866
Annualized Savings per Reclamation Acre[2]	$74	Present Value Total Savings per Acre[2]	$522

Costs expressed in 1998 Dollars

[1] *Discount Rate: 0.07*

[2] *Based on 381 disturbed acres*

Table 5h: Cost of Meeting Numeric Limits vs. Cost to Implement Alternative Sediment Control BMPs for the Northern Plains Model Mine (adapted and revised from WCMWG, 2001)

Year	Numeric Limitations				Alternate Sediment Control Measures			
	Capital	Operating	Total	Present Value[1]	Capital	Operating	Total	Present Value[1]
1	$513,552	$11,682	$525,234	$525,234	$432,631	$3,677	$436,309	$436,309
2	43,577	66,628	110,204	102,995	43,577	58,646	102,223	95,536
3	0	37,426	37,426	32,689	0	29,433	29,433	25,708
4	0	68,723	68,723	56,099	0	60,808	60,808	49,638
5	0	46,582	46,582	35,537	57,317	3,563	60,880	46,445
6	0	42,408	42,408	30,236	-	-	-	-
7	0	11,568	11,568	7,709	-	-	-	-
8	0	11,568	11,568	7,204	-	-	-	-
9	0	12,699	12,699	7,391	-	-	-	-
10	140,054	14,224	154,278	83,917	-	-	-	-
Total (not discounted)	$697,183	$323,508	$1,020,691	$889,011	$533,525	$156,127	$689,651	$653,636
Annualized @ 7% over 10 years				$126,575				$93,063

Annualized Savings	$33,512	Present Value Total Savings	$235,375
Annualized Savings per Reclamation Acre[2]	$88	Present Value Total Savings per Acre[2]	$618

Costs expressed in 1998 Dollars

[1] *Discount Rate: 0.07*

[2] *Based on 381 disturbed acres*

5.3 Case Study 3 (Western Coal Mining Work Group, 2000b)

This case study contains surface water runoff modeling and performance-cost-benefit information regarding alternative sediment control technologies for non-process areas in the Western Alkaline Coal Mining Subcategory (WCMWG, 2000b). The areas include:

- **Brushing and grubbing** - removal or incorporation of woody plant material that would interfere with soil salvage operations
- **Soil salvage** - soil reconstruction materials (soil, subsoil, and neutral dressing), and
- **Soil stockpiling activities** - activities where soil resources are stockpiled for future use in soil reconstruction or reclamation

Land affected by these activities are considered to be appropriate for the implementation of alternate sediment control technologies when sediment is the only constituent of concern in non-process surface water runoff. This case study contains an analysis comparing the predicted performance-costs-benefits associated with sedimentation pond systems to the use of alternate BMP sediment controls to minimize impacts to the hydrological and fluvial balance of western coal mine watersheds.

Modeling was conducted for a representative mine in the arid/semiarid western United States using the following three scenarios:

1) Pre-mining background - A characterization prior to surface disturbance by mining and reclamation activities;

2) Numeric Limitations - Modeling and design of a sediment control system that meets numeric limitations for runoff from areas where pre-mining activities supporting reclamation are being conducted; and

3) Alternate Sediment Control Measures - Modeling and design of a BMP-based alternate sediment control system that meets background sediment yield standards for runoff from areas where pre-mining activities supporting reclamation are conducted.

Modeling of conditions prior to surface disturbance by mining was conducted to characterize pre-mining background water quality, soil loss rates, and sediment yield. The modeled values serve as a benchmark, establishing standards for the alternate sediment control system.

Non-process areas were modeled using 1) alternate sediment control measures, and 2) a treatment system designed to meet a maximum daily TSS concentration of 70 mg/L and a 30-day average TSS concentration of 35 mg/L.

NMA developed a third scenario using alternative erosion and sediment control techniques. The alternate sediment control BMPs used in the modeling effort were:

- Silt fences
- Infiltration berms
- Porous rock check dams
- Rock diversions
- Rotoclearing or chipping

The same contour mapping and corresponding hydrographic and soils databases that were developed for Case Study 1 were used to support modeling of the hydrology and sedimentology of a typical watershed in the arid/semiarid western United States.

5.3.1 Modeling Results

Average annual erosion quantities were predicted based on the RUSLE model version 1.06. Input parameter values for the modeling effort were based on vegetation, soils, and surface configurations obtained from existing case study mines and mine permits. RUSLE variables were input to SEDCAD 4.0 to model watershed sedimentology. Since hydrologic conditions were also modeled (analysis of a 10-year, 24-hour design storm), all three scenarios were assessed with SEDCAD 4.0.

40 CFR Part 434, Subcategory H requires establishment of pre-mining background watershed conditions, against which the adequacy of the sediment control system is measured. Use of alternate BMP sediment control systems during mining and reclamation facilitates deployment of controls designed to mimic site-specific, pre-mining background watershed conditions. Mine modeling of pre-mining activities supporting reclamation was performed in order to characterize potential benefits of these systems.

Modeling erosion and sediment controls for pre-mining activities produced the results shown in Table 5i.

Table 5i: Comparison of Hydrology and Sedimentology Results (Western Coal Mining Work Group, 2000b)

	Pre-mining Background	Reclaimed to Meet Numeric Limits[1]		Reclaimed Under Alternate Sediment Control Measures	
	Result	Result	% Change from Pre-mining	Result	% Change from Pre-mining
Total Contributing Area (acre)	291	266	-9	291	0
Peak Discharge (cfs) (10 year, 24-hr storm event)	103	7	-93	93[2]	-10
Total Runoff Volume (acre-ft) (10 year, 24-hr storm event)	12	16[3]	+33	18	+50
Sediment (tons) (10 year, 24-hr storm event)	1,067	0	-100	586	-45
Sediment Loss (tons/acre)	3.7	0	-100	2.0	-46
Peak Sediment (mg/L) (10 year, 24-hr storm event)	129,300	40	-100	119,200	-8
Peak Settleable Solids (ml/L) (10 year, 24-hr storm event)	58	0	-100	24	-65
Settleable Solids (ml/L) (24-hr Volume Weighted) (10 year, 24-hr storm event)	30	0	-100	5	-83

[1]Assumes pond is filled to design storage capacity with 1 year of transported sediment.

[2] Four porous rock check dams were used as BMPs. SEDCAD 4.0 does not give credit for reduction or attenuation in peak flow when using the check dam structure analysis option. The two upstream check dams (Stru#1 and Stru#2) were very small and on steep gradients and were modeled as check dams. The two larger dams (Stru#8 and Stru#12) were on flatter gradients and were modeled as ponds to take peak flow attenuation into account.

[3]Sediment pond outflow devices include a fixed siphon (which was modeled) and a gate pipe with a floating inlet designed to remove water from the pond by decanting water from near the pond surface.

The most important modeling results are for peak discharge and peak sediment concentration. The BMP treatment system reduced peak discharge by only 10% below background levels, while the system for treatment to numeric limitations reduced the peak discharge by 93% below background levels.

Prolonged changes in peak sediment concentrations are capable of disrupting fluvial balances and introducing degradation or aggradation in the receiving channel. The proposed BMP treatment system achieved peak sediment concentrations approximately 8% less than pre-mining background levels, while the current subcategory treatment system had peak sediment concentrations that were near zero to comply with the effluent standard of 35/70 mg/L TSS. This is a direct result of capturing almost 100% of the sediment in the sediment pond.

Sediment delivery from the BMP treatment sediment control system more closely approximated background at 2.0 tons (a reduction of 1.7 tons) vs. the treatment system's delivery of 0 tons (a reduction of 3.7 tons). Settleable solids levels released from the BMP treatment system were a little more than half the background conditions, while the treatment system reduction was almost 100%.

5.3.2 Costs

An analysis of costs was conducted under both the sediment control system and the system designed to treat to numeric limitations. Cost assessment was based on capital costs (design, construction, and removal) and operating costs (inspection, maintenance, and operation) associated with the sedimentation pond system and the BMP-based system used over the two-year development period. These costs were developed for the two-year period of pre-mining activities supporting reclamation. A summary of the costs associated with both the current subcategory and proposed subcategory options are presented in Table 5j.

The present value of the reclamation costs over the two-year premining period (discounting at seven percent) is $463,582 for the existing guideline and $202,190 for the proposed subcategory, or a present value total savings of $261,392 over two years. This represents a 56 percent overall reduction in costs, or $2,489 is saving per disturbed acres. The annualized savings are $135,115 (annualized at seven percent), or $1,287 annualized savings per acre for the 105 disturbed acres.

Table 5j: Cost of Sedimentation Pond System vs. Cost to Implement Alternative Sediment Controls (adapted and revised from WCMWG, 2000b)

Year	Sedimentation Pond System				Alternate Sediment Control Technologies			
	Capital	Operating	Total	Present Value[1]	Capital	Operating	Total	Present Value[1]
1	$420,512	$24,845	$445,357	$445,357	$174,050	$9,177	$ 83,227	$183,227
2	-	19,501	19,501	18,225	9,718	10,572	20,290	18,963
Total (not discounted)	$420,512	$44,346	$464,858	$463,582	$183,768	$19,749	$203,517	$202,190
Annualized @ 7% over 2 years				$239,629				$104,514

Annualized Savings	$135,115	Present Value Total Savings	$61,392
Annualized Savings per Reclamation Acre[2]	$1,287	Present Value Total Savings per Acre[2]	$2,489

Costs expressed in 1998 Dollars

[1] Discount Rate: 0.07

[2] Based on 105 disturbed acres.

5.4 Case Study 4 (Bridger Coal Company, Jim Bridger Mine)

Wyoming Department of Environmental Quality, Land Quality Division Rules and Regulations, Chapter IV, Section 3g(1) states that exemptions to the use of sedimentation ponds may be granted where, by the use of alternative sediment control (ASC) measures, mine drainage will not degrade receiving waters. The Jim Bridger Mine located in southwestern Wyoming, has successfully used ASC measures, in addition to several sediment ponds, to treat disturbed area runoff and prevent degradation of local stream water quality since 1984.

Case Study 4 presents a summary of a Jim Bridger Mine study provided by the Western Coal Mining Work Group (Bridger Coal Company, 1987). Bridger Coal Company began coal production in 1974. The Bridger mine is located in a desert located 28 miles northeast of Rock Springs in southwest Wyoming. Mean annual precipitation is 6-8 inches, and the mean frost free period is 100 days. High winds are frequent and evapotranspiration is high. Some soils and spoils are saline or sodic. The local receiving water consists of ephemeral streams.

An experimental practice for a portion of the mine was initiated in 1983 to test the effectiveness of alternate sediment control techniques compared to sediment ponds for preventing additional contributions of sediment to receiving streams. The alternate sediment control practices became standard in 1987, and are still in use today. The effectiveness of alternate sediment control techniques continues to be monitored.

5.4.1 Justification of Alternate Sediment Controls

Initial water quality data available for receiving streams are presented in Figure 5b. The data indicate that undisturbed mine area runoff is high in suspended solids. Data from single stage sediment samples show total suspended solids (TSS) concentrations of 110 to 820,000 mg/L for discharges from 1 to 500 cubic feet per second (cfs). The highest values measured by single stage sediment samples were enriched in coarse sediment by continued circulation during the runoff event. However, values of 800,000 mg/L indicate that sediment transport is high.

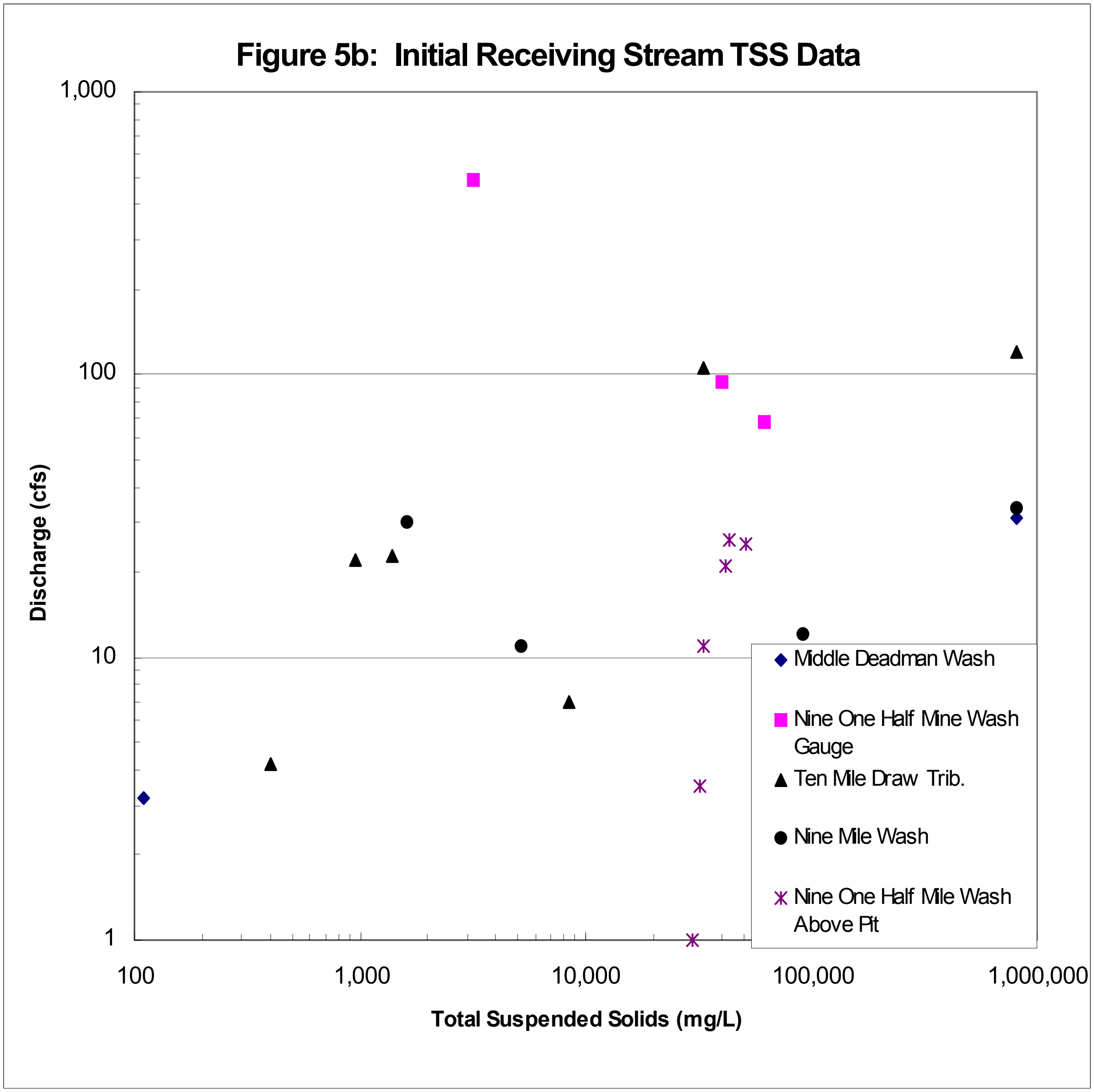


Figure 5b: Initial Receiving Stream TSS Data
1,000
100
10
1
Discharge (cfs)
100
1,000
10,000
100,000
1,000,000
Total Suspended Solids (mg/L)
Middle Deadman Wash
Nine One Half Mine Wash Gauge
Ten Mile Draw Trib.
Nine Mile Wash
Nine One Half Mile Wash Above Pit

Logistical concerns regarding sediment ponds were important in the decision to implement alternate sediment control techniques. The extensive mining area and the drainage density would necessitate approximately 200 ponds to control all mining disturbed runoff over the life of the mine. This would entail disturbing over 400 additional acres. Such land disturbance is essentially eliminated by use of alternate sediment control techniques.

The benefits of the use of alternate sediment controls instead of sediment ponds are:

- Channel degradation below dams, produced by the discharge of unnaturally clear and erosive water, is precluded;
- Additional disturbance due to dam and pond construction is avoided; and
- With the elimination of impoundment storage time, seepage, and evaporation, there is less disruption of natural stream flows.

5.4.2 Description of Alternate Sediment Control Techniques

Several techniques are used by the Bridger Coal Company to limit sediment discharge from mined land to background levels (Hargis, 1995). Most of these techniques are appropriate for small drainage areas. Drainage from larger areas can be diverted to the pit floor where it can be stored and used for road watering. The first group of techniques involves preventing the runoff from leaving the disturbed areas. These techniques include:

- Berms
- Diversion ditches
- Toe ditches
- Small catchments
- Drainage to pit floor via haul roads and ramps

The second group of techniques involves the use of rock check dams or hay bales for the purpose of filtering and temporarily detaining runoff water until some of its sediment load settles. Check dam size is determined by using the SEDIMOT II computer program. These materials are used a short distance downstream from the disturbed land. They are installed before soil removal and maintained while the disturbed drainage area is unstable.

A third group of techniques involves appropriate mine land reclamation practices and includes:

- Prudent geomorphic design
- Reconstruction of complex slopes
- Restoration of drainage density
- Roughening of soil surface
- Mulching
- Contour farming
- Timely establishment of permanent vegetative cover

Bridger Coal Company continuously evaluates the effectiveness of sediment control technologies that are in place at this site as well as the predicted effectiveness of additional techniques, and modifies the alternate sediment control plan appropriately when necessary.

5.4.3 Alternate Sediment Control Design

In order to determine the most appropriate ASC techniques for each mining area, Bridger Coal Company used the computer models SEDIMOT II and SEDCAD. These models allow evaluation of disturbed area runoff prior to the disturbance and simulate the various alternate sediment control s. These models also allow the determination of alternate sediment control size and location necessary to reduce the sediment discharge to levels below the receiving stream water quality. Once an alternate sediment control plan has been designed and implemented, a monitoring program is then used to determine the effectiveness of the control techniques and record water quality degradation, should any occur.

Prior to the original permit application at this site, surface water quality data showed that TSS was the only parameter that was consistently high, and was, therefore, of concern to in stream water quality. These data are presented in Table 5k. For this reason, and because of the importance of sediment transport in fluvial systems, TSS is the primary water quality parameter considered in design of alternate sediment control techniques.

Table 5k: Pre-mining Surface Water Quality Data

Site	Type	Date	Iron (mg/L)	Manganese (mg/L)	Field pH	TSS (mg/L)	Discharge (cfs)
BCTR	PD	04/14/80	1.47	0.044	7.20	411.0	-
BCTR	PD	05/15/80	1.32	0.048	9.00	303.0	-
L10MD	SC	01/17/80	1.42	0.190	-	182.0	-
L10MD	SC	04/14/80	0.52	0.033	-	1240.0	-
MDW	SC	06/17/80	475.00	7.600	-	21750.0	-
MDW	SC	05/14/80	1.08	0.449	-	66152.0	-
MDW	SS	06/17/80	475.00	7.600	-	21750.0	-
UDW	SS	03/17/80	1.15	0.430	7.80	1672.0	-
U10MD	SC	04/26/79	0.55	0.180	-	24.0	-
U10MD	SC	05/31/79	0.47	0.050	8.40	40.0	-
U10MD	SC	08/22/79	4.76	0.120	7.30	79.0	-
U10MD	SC	10/24/79	0.06	-	8.00	52.0	-
U10MD	SC	03/11/80	0.16	0.064	7.70	68.0	-
U10MD	SC	04/14/80	0.21	0.029	8.30	916.0	-
U10MD	SS	03/19/81	1.24	0.190	-	56.0	-
10MDT	SC	04/16/80	2.78	0.090	-	8728.0	-
10MDT	SC	06/17/80	165.00	3.200	-	8141.0	18.0
10MDT	SS	03/13/80	164.00	2.100	-	1532.0	28.0
10MDT	SS	04/16/80	180.65	2.715	-	8728.0	1.0
10MR3	PD	04/26/79	2.40	0.050	7.80	68.0	-
10MR3	PD	08/22/79	23.60	0.260	8.20	275.0	-
10MR3	PD	09/25/79	32.00	0.440	6.00	816.0	-
10MR3	PD	04/16/80	0.56	0.210	8.80	71.0	-
10MR3	PD	05/15/80	0.50	0.200	7.30	418.0	-

Site	Type	Date	Iron (mg/L)	Manganese (mg/L)	Field pH	TSS (mg/L)	Discharge (cfs)
10MR3	PD	06/18/80	4.12	0.075	7.90	37.0	-
10MR3	PD	07/10/80	1.27	0.130	7.50	65.0	-
10MR3	PD	08/04/80	3.04	0.385	7.20	180.0	-
10MR3	PD	09/05/80	4.20	0.410	7.40	368.0	-
10MR3	PD	10/02/80	1.42	0.020	8.30	438.0	-
10MR3	PD	11/06/80	3.15	0.332	8.75	-	-
10MR4	PD	04/26/79	31.00	0.370	-	620.0	-
10MR4	PD	08/22/79	16.00	0.190	7.80	348.0	-
10MR4	PD	09/25/79	1.67	0.270	6.20	30.0	-
10MR4	PD	10/24/79	1.59	0.000	7.40	36.0	-
10MR4	PD	04/14/80	0.47	0.120	7.40	19.5	-
10MR4	SC	05/15/80	0.46	0.210	7.50	715.0	-
10MR4	SS	06/18/80	55.50	1.570	6.80	1700.0	-
9.5MD	SS	04/15/80	0.34	0.450	-	4516.0	-
9.5MD	SS	08/22/79	1470.00	22.100	-	3211.0	-
9.5MW	SC	07/29/81	936.00	-	-	61600.0	72.0
9.5MW	SS	09/15/81	930.00	-	-	38700.0	104.0
9MW	SS	06/17/80	140.00	3.500	-	11660.0	-
9MW	SS	08/21/79	520.00	12.100	-	5373.0	-
9MW	SS	03/08/80	42.20	0.920	-	1768.0	19.7
9MW	SS	07/15/81	1050.00	-	-	93600.0	-

PD = Pond; SC = Stream Channels; and SS = Sediment Sampling Stations.

In the SEDIMOT II and SEDCAD models, the SCS curve number is used for flow runoff calculations; the Modified Universal Soil Loss Equation (MUSLE) is used for soil loss calculations; the Muskingum method is used to route water flow; Williams Model I is used to route sediment in channels; and Yang's unit stream power equation is used to route sediment overland. Application of these models allows increased temporal and spatial variability to be incorporated into the analysis, and allows for channel segments and subwatershed areas to be specified to simulate individual contributions to the total basin output.

For this site, a database containing TSS concentrations in a small ephemeral stream during pre-mining, undisturbed conditions existed prior to the initial alternate sediment control application submittal. Data from this database are presented in Table 5l. From this database, a design TSS input value for the SEDIMOT II/SEDCAD simulations was calculated. The arithmetic average of these data (30,000 mg/L) was used as a design criterion to determine the location and size of the alternate sediment control structures. Preferably, disturbed area runoff should be near or below the mean TSS concentration of the observed data (30,000 mg/L). The actual impact of the mine runoff on the receiving stream water quality was determined from the data collected from the alternate sediment control monitoring program.

The actual alternate sediment controls selected differ for each reclaimed area and are determined by site-specific analysis. As part of this analysis, the company uses SEDIMOT II/SEDCAD to model the effects of seven alternate sediment control techniques, simulated in sequence as presented in Table 5m. The sequence is determined by experience with alternate sediment control effectiveness in reducing sediment discharges.

Table 5l: Existing Database, Undisturbed TSS Concentration Data

Location	Date	TSS (mg/L)	Peak Monthly Flow (cfs)	10-Yr.-24-hr. Peak Discharge (cfs)
Nine Mile Wash	08/21/79	5,373.0	13.0	1,646.0
	03/08/80	1,768.0	35.4	
	10/05/80	37,700.0	50.4	
	10/05/80	22,640.0	50.4	
	07/15/81	93,600.0	12.0	
	08/09/82	34,050.0	55.0	
9.5 Mile Wash @ Crest Gage	08/22/79	3,211.0	375.0	625.0
	07/29/81	61,600.0	72.0	
	09/15/81	38,700.0	104.0	
	08/05/82	95,700.0	120.0	
Middle Deadman Wash	5/14/80	66,152.0	5.0	887.0
	06/17/80	21,750.0	8.0	
9.5 Mile Wash @ Temp. Recording Sta.	09/14/82	53,540.0	27.0	
		44,500.0	28.0	
		42,920.0	22.0	
		34,660.0	11.0	
		32,780.0	4.0	
		29,420.0	1.0	
	9/24/82	3,155.0	NA[1]	
		17,000.0	NA[1]	
		20,300.0	NA[1]	
		15,540.0	NA[1]	
		24,840.0	NA[1]	
		20,490.0	NA[1]	
		17,150.0	NA[1]	
		19,900.0	NA[1]	
		16,120.0	NA[1]	
		20,020.0	NA[1]	
		14,670.0	NA[1]	
		13,340.0	NA[1]	
		36,860.0	NA[1]	
		8,160.0	NA[1]	
		14,800.0	NA[1]	
		Average = 29,770	**(Round to 30,000)**	

[1] Not available, hydrograph not recorded.

Table 5m: Order of Simulation of Sediment Control Best Management Practices

Order of Implementation in Design	Sediment Control Technique
1	Rock Check Dams
2	Interceptor Ditch (Contour Ditch)
3	Contour Berms
4	Vegetative Buffer Strip
5	Toe Drain Ditch
6	Temporary Barrier
7	Benches

5.4.4 Monitoring Program

Monitoring is conducted during runoff events between May 1 and September 30 (when temperatures are above freezing). Each monitoring station is serviced generally after each storm, and at least once per month, from May through September. In addition, checks are performed every two weeks from May through September.

Through the first three mining periods, eight paired watersheds (four pairs) and one control station were equipped with automatic pump samplers and manometers. Each watershed pair consisted of one disturbed watershed treated with alternate sediment controls and an undisturbed watershed. The nine sampling stations were:

SWPS-2 — Station SWPS-2 was a control watershed location on a tributary of Deadman Wash. This station was impacted by mining in 1990 and decommissioned in 1991. However, no data were collected because very little runoff was generated by the small storms that occurred in the watershed since the station was installed.

SWPS-3 — Station SWPS-3 is the upstream receiving stream station located near the upper mining limit. SWPS-3 is located on Deadman Wash and provides pre-mining, undisturbed data.

SWPS-4 — Station SWPS-4 was located on Deadman Wash, downstream from SWPS-3. SWPS-4 was the disturbed watershed paired with SWPS-3 during the experimental period (1984-1987). The site was decommissioned in 1987 and mined through in 1988.

SWPS-7 Station SWPS-7 was located on Deadman Wash, just above the outlet of the SWPS-8 watershed. SWPS-7 was the undisturbed watershed paired with SWPS-8 during the experimental period (1984-1987). The site was decommissioned in 1987.

SWPS-8 Station SWPS-8 monitors a disturbed watershed on a tributary of Deadman Wash. SWPS-8 is located approximately 1,000 feet upstream from Deadman Wash.

SWPS-9 Station SWPS-9 is a Deadman Wash downstream receiving station that is located approximately 100 feet upstream from the confluence of Deadman Wash and Nine Mile Draw.

SWPS-10 Station SWPS-10 is a disturbed watershed location on Nine Mile Draw. This location is located approximately 300 feet upstream from the confluence of Nine Mile Draw and Deadman Wash.

SWPS-13 Station SWPS-13 is upstream from the pit and represents the receiving stream.

SWPS-14 Station SWPS-14 is downstream of all mining disturbance in the Ten Mile Draw drainage basin.

5.4.5 Data Reduction

During the first permit term, the discharge monitoring data were reduced using standard U.S. Geological Survey (USGS) procedures for continuous sediment and water stage data. The reduced data were then analyzed using either a covariance test or a modified Student's t-test in order to determine whether degradation occurred in the receiving stream as a result of the disturbed area runoff.

During the second and all subsequent permit terms, the data reduction procedure followed Porterfield (1972). This procedure is summarized as follows:

1. The stage recorder chart is adjusted for applicable pen, data, or time corrections.
2. Discrete sediment sample data are used to construct a continuous temporal sediment concentration graph on the same scale as the flow record.

3. Water stage and sediment graphs are subdivided by mid-intervals into discrete water discharge, sediment concentration, and sediment discharge values. In order to avoid biasing the data in subsequent analyses, equal time intervals are used for the disturbed stream and receiving stream subdivisions.
4. The subdivided water discharge and sediment discharge data are used to calculate storm sediment yields in tons per acre and storm water yields in acre-feet per square mile.
5. A log-log data plot of all monitoring stations is prepared with storm sediment yield plotted against storm water yield.

5.4.6 Data Analysis

Once data have been reduced they are analyzed to determine if degradation has occurred (i.e., sediment yield has increased over background conditions). During the first permit term (1984-1987), the discharge monitoring data were reduced using standard USGS procedures for continuous sediment and water stage data. The allowable TSS change criteria initially were based on a statistical comparison of storm sediment concentrations in the receiving stream before and after addition of the disturbed area runoff. Sediment data were analyzed with either a covariance test (for multiple pairs), or a modified Student's t-test (for a single pair of TSS data points) in order to determine whether the receiving stream (Deadman Wash) was degraded by runoff from the disturbed area. Since no degradation had been detected in over 65 storms, alternate sediment control techniques were determined to be successful.

A simpler method for assessing differences in TSS concentrations between paired watersheds was approved for the second and subsequent terms of the permit. First, instantaneous TSS concentrations and flow rates are collected at adequate intervals to accurately calculate storm water and sediment yield. An example of reduced storm yield data is presented in Table 5n.

Table 5n: Example Water and Sediment Yield Data (1984 - 1998)

Station	Date	Stream Type	Water Yield (acre-ft/mi^2)	Sediment Yield (tons/acre)
SWPS-3	7/31/84	Receiving	1.477484022	0.050618459
SWPS-3	6/25/85	Receiving	0.005176922	0.0000418
SWPS-3	7/18/85	Receiving	0.031431064	0.00089235
SWPS-3	7/23/85	Receiving	0.11673182	0.005699971
SWPS-3	7/30/85	Receiving	0.080180455	0.001962336
SWPS-3	4/24/86	Receiving	0.002708907	0.0000293
SWPS-3	5/8/86	Receiving	0.009636635	0.0000606
SWPS-3	7/4/86	Receiving	0.010107986	0.0007701
SWPS-3	8/29/86	Receiving	0.003897468	0.00012434
SWPS-3	9/24/86	Receiving	0.001839712	0.0000272
SWPS-3	9/26/86	Receiving	0.002459572	0.0000167
SWPS-3	9/27/86	Receiving	0.001592364	0.000009
SWPS-3	5/29/87	Receiving	0.02346527	0.00057052
SWPS-3	5/30/87	Receiving	0.002834567	0.0000439
SWPS-3	6/9/87	Receiving	0.025076508	0.0005538
SWPS-3	9/3/87	Receiving	0.007832187	0.00028004
SWPS-3	9/4/87	Receiving	0.021765622	0.00035631
SWPS-3	7/12/89	Receiving	0.00843516	0.00030093
SWPS-3	9/19/89	Receiving	0.010161131	0.00017763
SWPS-3	8/21/90	Receiving	0.001368857	0.000008
SWPS-3	5/22/91	Receiving	0.011213602	0.00036676
SWPS-3	6/1/91	Receiving	0.519122156	0.012856543
SWPS-3	6/13/91	Receiving	0.03358617	0.00099266
SWPS-3	7/25/91	Receiving	0.12759526	0.00192681
SWPS-3	9/9/91	Receiving	0.034409669	0.001002066
SWPS-3	9/29/91	Receiving	0.13113313	0.004085589
SWPS-3	7/11/92	Receiving	0.333143	0.004893302
SWPS-3	7/21/92	Receiving	0.063889	0.001587215
SWPS-3	6/3/93	Receiving	0.094653	0.00055171
SWPS-3	6/17/93	Receiving	0.16531	0.00061545
SWPS-3	6/26/93	Receiving	0.14757	0.004199484
SWPS-3	9/12/94	Receiving	0.005984	0.00011808
SWPS-3	5/25/96	Receiving	0.014834	0.0000742
SWPS-3	9/8/95	Receiving	0.090383	0.002519272
SWPS-4	7/31/84	Disturbed	1.281434215	0.059088767
SWPS-4	7/18/85	Disturbed	0.038092331	0.00066273
SWPS-4	7/23/85	Disturbed	0.089620306	0.006017068
SWPS-4	7/30/85	Disturbed	1.315367177	0.037101028
SWPS-4	7/4/86	Disturbed	0.017723258	0.00096693

Station	**Date**	**Stream Type**	**Water Yield (acre-ft/mi^2)**	**Sediment Yield (tons/acre)**
SWPS-4	9/3/87	Disturbed	0.036651076	0.002640955
SWPS-4	9/4/87	Disturbed	0.051385958	0.001527354
SWPS-7	7/31/84	Receiving	0.883773652	0.03245597
SWPS-7	8/6/84	Receiving	0.018663956	0.00091022
SWPS-7	8/18/84	Receiving	0.008212654	0.00029353
SWPS-7	9/6/84	Receiving	0.078186652	0.002446697
SWPS-7	7/18/85	Receiving	0.026335062	0.00052174
SWPS-7	7/20/85	Receiving	0.037043061	0.001852661
SWPS-7	7/23/85	Receiving	0.080330902	0.004302842
SWPS-7	7/30/85	Receiving	1.64197228	0.036970469
SWPS-7	7/4/86	Receiving	0.031810992	0.001072226
SWPS-7	5/29/87	Receiving	0.049678773	0.002706261
SWPS-7	6/9/87	Receiving	0.010749402	0.00050693
SWPS-7	9/3/87	Receiving	0.017177596	0.0008806
SWPS-7	9/4/87	Receiving	0.06342408	0.001558256
SWPS-8	7/9/84	Disturbed	0.864063707	0.039664882
SWPS-8	7/31/84	Disturbed	2.989430677	0.346925851
SWPS-8	8/6/84	Disturbed	1.377395402	0.128622236
SWPS-8	8/18/84	Disturbed	0.65060337	0.029959021
SWPS-8	9/6/84	Disturbed	2.053912776	0.0679606
SWPS-8	7/30/85	Disturbed	7.646761495	0.747331783
SWPS-8	5/29/87	Disturbed	0.942419621	0.034361881
SWPS-8	7/23/89	Disturbed	16.7603059	0.85378317
SWPS-8	9/18/89	Disturbed	1.953010004	0.05122973
SWPS-8	7/20/90	Disturbed	0.756138294	0.017944103
SWPS-8	9/4/90	Disturbed	24.80262338	0.729661636
SWPS-8	7/12/92	Disturbed	3.338507	0.040114953
SWPS-8	7/21/92	Disturbed	0.386208	0.03935179
SWPS-8	6/7/93	Disturbed	1.28865	0.008883994
SWPS-8	7/26/93	Disturbed	2.903206	0.129072306
SWPS-8	9/7/95	Disturbed	3.5058	0.220394066
SWPS-8	9/21/97	Disturbed	1.292154	0.048861472
SWPS-9	7/31/84	Receiving	0.968139808	0.066406744
SWPS-9	8/6/84	Receiving	0.030162507	0.001983688
SWPS-9	9/6/84	Receiving	0.340016234	0.023758994
SWPS-9	7/18/85	Receiving	0.037446771	0.00087062
SWPS-9	7/20/85	Receiving	0.393764689	0.024798275
SWPS-9	7/23/85	Receiving	0.145318019	0.005443206
SWPS-9	7/30/85	Receiving	2.115498217	0.129639835
SWPS-9	6/9/87	Receiving	0.046868004	0.003246825
SWPS-9	9/19/89	Receiving	0.60228965	0.013080951
SWPS-9	8/4/90	Receiving	0.377490999	0.009658689

Station	Date	Stream Type	Water Yield (acre-ft/mi^2)	Sediment Yield (tons/acre)
SWPS-9	5/15/91	Receiving	0.524044071	0.00476637
SWPS-9	8/4/91	Receiving	0.137681387	0.003731229
SWPS-9	9/7/95	Receiving	1.280506	0.037841673
SWPS-9	9/21/97	Receiving	0.808959	0.036334021
SWPS-9	7/24/98	Receiving	0.233039	0.006275786
SWPS-9	7/25/98	Receiving	0.114991	0.003876858
SWPS-9	8/3/98	Receiving	0.070143	0.003449813
SWPS-10	7/21/84	Disturbed	0.027840712	0.00060744
SWPS-10	7/31/84	Disturbed	1.273303295	0.063190439
SWPS-10	8/1/84	Disturbed	0.059938324	0.001226025
SWPS-10	8/4/84	Disturbed	0.024953331	0.00072447
SWPS-10	8/23/84	Disturbed	0.187992353	0.004881808
SWPS-10	9/6/84	Disturbed	1.220188727	0.024843723
SWPS-10	9/13/84	Disturbed	0.29014207	0.01063298
SWPS-10	9/21/84	Disturbed	0.086033362	0.00068546
SWPS-10	6/25/85	Disturbed	0.225655459	0.004346816
SWPS-10	7/18/85	Disturbed	0.088624058	0.003332559
SWPS-10	7/20/85	Disturbed	1.274837051	0.057595307
SWPS-10	7/23/85	Disturbed	0.490645525	0.016545764
SWPS-10	7/30/85	Disturbed	1.892771051	0.07519991
SWPS-10	9/2/85	Disturbed	0.301326036	0.014233035
SWPS-10	9/11/85	Disturbed	0.224095213	0.004608739
SWPS-10	9/19/85	Disturbed	0.285482526	0.00433567
SWPS-10	7/4/86	Disturbed	0.065318389	0.003137509
SWPS-10	7/9/86	Disturbed	0.03566578	0.00096967
SWPS-10	9/8/86	Disturbed	0.040836576	0.001148005
SWPS-10	7/11/87	Disturbed	0.045726581	0.00097525
SWPS-10	9/4/87	Disturbed	1.077011708	0.01375377
SWPS-10	7/26/88	Disturbed	0.345285	0.023645
SWPS-10	8/3/88	Disturbed	0.881732	0.034852
SWPS-10	7/12/89	Disturbed	10.2879986	0.4594194
SWPS-10	7/23/89	Disturbed	9.266459047	0.493653359
SWPS-10	9/18/89	Disturbed	0.204264997	0.007283703
SWPS-10	9/19/89	Disturbed	1.70304627	0.026197923
SWPS-10	9/20/89	Disturbed	0.350679062	0.004809361
SWPS-10	7/20/90	Disturbed	0.005629069	0.00015047
SWPS-10	7/24/90	Disturbed	6.277730829	0.26287646
SWPS-10	8/4/90	Disturbed	0.207790781	0.010900476
SWPS-10	8/30/90	Disturbed	1.216872212	0.064923592
SWPS-10	6/1/91	Disturbed	1.261933901	0.079357249
SWPS-10	6/13/91	Disturbed	0.289479827	0.013982257
SWPS-10	8/27/91	Disturbed	0.068529	0.00109785

Station	**Date**	**Stream Type**	**Water Yield (acre-ft/mi^2)**	**Sediment Yield (tons/acre)**
SWPS-10	9/9/91	Disturbed	0.040127	0.00635304
SWPS-10	9/29/91	Disturbed	0.019763991	0.00064645
SWPS-10	6/3/93	Disturbed	0.38052	0.006587097
SWPS-10	6/17/93	Disturbed	0.820869	0.007857705
SWPS-10	7/26/93	Disturbed	0.576255	0.019192863
SWPS-10	8/11/93	Disturbed	0.077249	0.002496633
SWPS-10	9/17/93	Disturbed	0.030802	0.00046812
SWPS-10	9/18/93	Disturbed	1.749732	0.02525054
SWPS-10	9/8/95	Disturbed	0.155225	0.004313379
SWPS-10	9/21/97	Disturbed	2.60624	0.107340165
SWPS-13	9/21/97	Receiving	9.156198	0.139136745
SWPS-14	9/21/97	Disturbed	0.039105	0.001971105
SWPS-14	7/29/98	Disturbed	0.009494	0.00032269

Next, the 95% prediction bands confining the regression equation $y = 0.0339(x)^{1.0925}$ are calculated using Equation 5a developed for predicting any value of "y" for a given "x" (Kleinbaum, 1978). Unit water and sediment yield are plotted with the 95% prediction intervals in Figure 5c, and a graphical comparison is made of the individual storm sediment yield relative to the general trend. Any points (storms) which fall inside the 95% prediction interval show that no significant variation from background sediment yield has occurred. If the disturbed monitoring station points (storms) plot above the predicted interval, degradation has technically occurred and mitigation measures are immediately taken. No unit sediment yields, of storms less than a 10-year, 24-hour event, plotted outside of the confidence bands between 1984 and 1998.

Equation 5a

$$y_0 = \overline{Y} + B_1(X_0 - \overline{X}) \pm t_{(n-2,\ 1-\alpha/2)} * S_{y/x} * \sqrt{(1 + \frac{1}{n} + \frac{(X_0 - \overline{X})^2}{(n-1) * S_X^2})}$$

Where:

$\overline{Y}$ = Mean of Y values

$\overline{X}$ = Mean of X values

B_1 = Coefficient of Regression Equation
X_0 = Value in Question
y_0 = Value in Question
$t_{(n-2,\ 1-\alpha/2)}$ = t statistic
n = Number of values
S_x^2 = Variance of x values

$$S_{y/x} = \sqrt{(\frac{n-1}{n-2}) * (S_y^2 - (B_1^2 * S_X^2))}$$

Where:

S_y^2 = Variance of Y values
n = Number of values
S_x^2 = Variance of X values
B_1 = Coefficient of Regression Equation

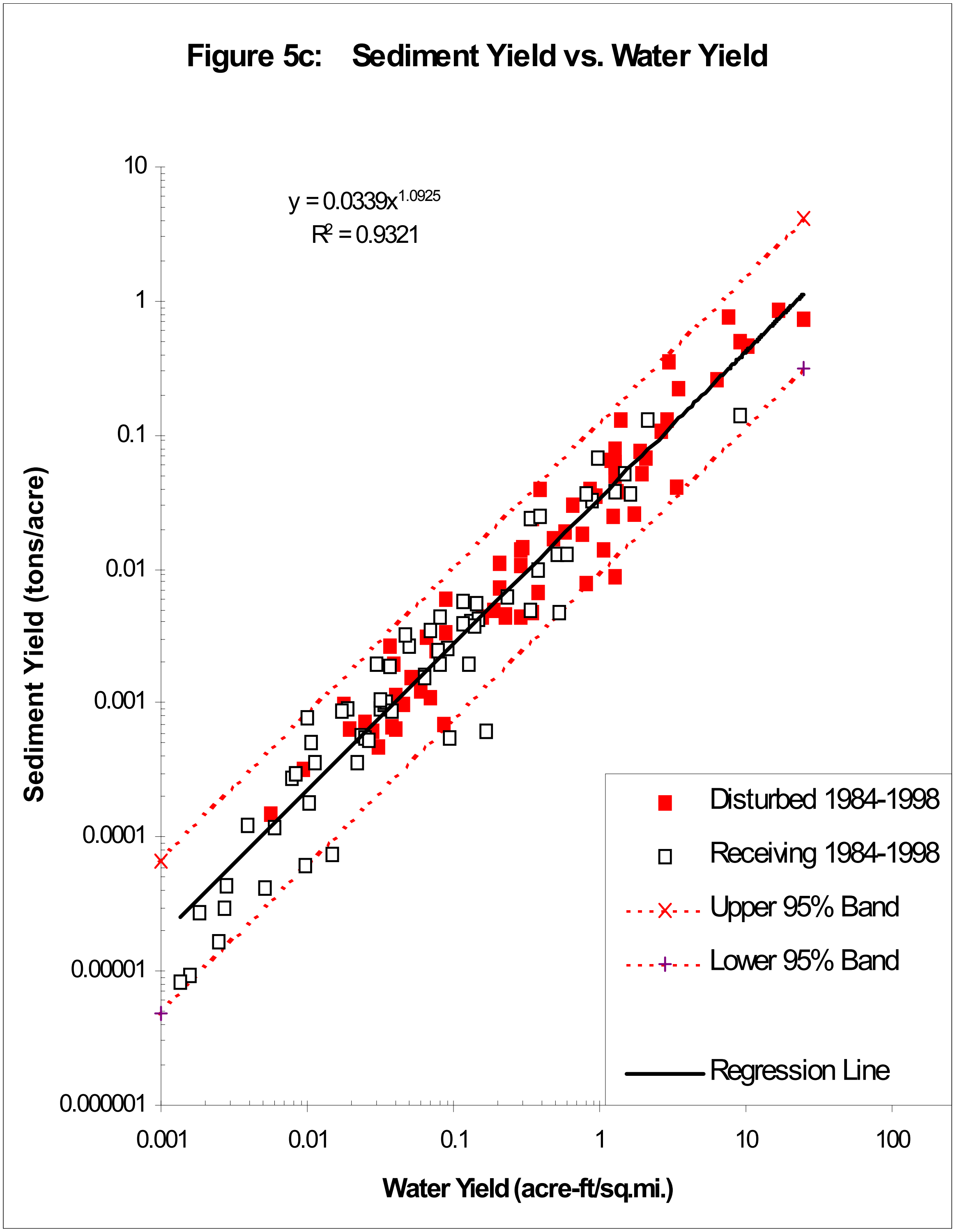


Figure 5c: Sediment Yield vs. Water Yield
y = 0.0339x^1.0925
R² = 0.9321
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Sediment Yield (tons/acre)
0.001
0.01
0.1
1
10
100
Water Yield (acre-ft/sq.mi.)
Disturbed 1984-1998
Receiving 1984-1998
Upper 95% Band
Lower 95% Band
Regression Line

To confirm that the use of alternate sediment controls is effective, Bridger also conducts annual surveys of the receiving streams. For example, Bridger Coal Company has conducted an annual survey of Nine and One-Half Mile Draw since 1987. The surveys include up to nine cross sections used to model Nine and One-Half Mile Draw. Two cross sections are located upstream from the final highwall, three are located in the reclaimed reach, and four are located downstream from the boxcut disturbance limit. Areas of head cutting, aggradation, or degradation are noted and reported each year. Based on data available (up to 1992), no aggradation or degradation has been detected downstream of the disturbance in Nine and One-Half Mile Draw.

5.4.7 Summary

Alternate sediment control technology is the primary means of sediment control at the Jim Bridger Mine. Ongoing surface water monitoring is used to detect the impact of mine disturbance treated with ASC techniques on receiving stream water quality. Analysis of monitoring results to date (1984-1998, Table 5m) has shown that, for storm events less than 10-year, 24-hour, background sediment levels have not been exceeded in disturbed watersheds. Analysis also has shown that sediment in disturbed watersheds correspond to sediment in receiving watersheds relative to sediment storage and release. These alternate sediment control design and monitoring methods have proven successful over a lengthy period of experimentation, evaluation, and application.

5.5 Case Study 5 (Water Engineering & Technology, Inc., 1990)

Case Study 5 summarizes a study performed for the Office of Surface Mining Reclamation and Enforcement during 1987-1989. This extensive project was jointly commissioned by the National Coal Association, the Office of Surface Mining Reclamation and Enforcement, BHP-Utah International Inc., Peabody Coal Company, and the Pittsburgh and Midway Coal Mining Company and was prepared by Water Engineering & Technology, Inc. (WET, Inc.). Details of the project are provided in the "Determination of Background Sediment Yield and Development of a Methodology for Assessing Alternative Sediment Control Technology at Surface Mines in the Semiarid West" (WET, Inc., 1990).

The study had four major objectives:

- Assess average annual background sediment yield at three mine sites based on surveying and computation of sediment accumulation in ponds;
- Evaluate available computer models for prediction of watershed runoff and sediment yield and select the model that best represents these processes at semiarid mine sites;
- Evaluate runoff and erosion response to rainfall using rainfall simulation testing on test plots (12 feet wide by 35 feet long). Use resulting data and information to calibrate and validate the computer model selected; and
- Apply the model to evaluate alternative sediment control practices and the ability of such practices to maintain erosion from reclaimed lands at or below comparable background erosion levels.

The study targeted sedimentation and erosion conditions in semiarid coal regions using data and information collected at the at Navajo Mine near Farmington, New Mexico (BHP-Utah International, Inc.), McKinley Mine near Gallup, New Mexico (Pittsburgh & Midway Coal Company), and the Black Mesa Mine near Kayenta, Arizona (Peabody Coal Company). All three mines are located in a semiarid environment where sediment yield is large and variable. Erosion generally results from the occurrence of short duration, high intensity rainfalls.

5.5.1 Background Sediment Yield

Surveys were conducted in ponds located near the McKinley and Navajo Mines to determine average sediment yields from undisturbed, semiarid watershed basins. No suitable ponds were identified at the Black Mesa Mine.

Eight ponds were surveyed near the McKinley Mine. Measured sediment yields (sedimentation rate, tons/acre/year) ranged from 0.11 to 3.2 tons/acre/year. The average sediment yield was 1.16 tons/acre/year with a standard deviation of 1.13 tons/acre/year. The lowest value of sediment yield was measured in a pond corresponding to basins with low relief and low hillslope gradients (MCM-3). The highest values of sediment yield were measured in ponds corresponding to basins with incised channels (MCM-1, 2, and 8). Ten ponds were surveyed near the Navajo Mine. Measured sediment yields for the Navajo Mine ponds ranged from 1.56 to 16.00 tons/acre/year. The average sediment yield was 4.82 tons/acre/year with a standard deviation of 4.54 tons/acre/year.

Sediment volume, sediment density, and sedimentation rate results from basins located near the McKinley and Navajo Mines are presented in Table 5o. The high variability in sediment yields is thought to be attributed in part to the age of the ponds (from 8 to 38 years), size of the basin drainage areas (averages are 0.17 and 0.64 square miles for Navajo and McKinley Mines, respectively), and types of soil (clay, sandy loam, loam, sandy clay loam, and clay loam).

Table 5o: Measured Sediment Yields at Navajo and McKinley Coal Mines

Pond	Sediment Volume (ft^3)	Drainage Area (acres)	Age (years)	Sediment Density (lbs/ft^3)	Sedimentation Rate (tons/acre/yr)
NM-2	152,440	109	8	107	9.36
NM-3	115,060	183	8	100	3.93
NM-4	39,110	42.2	8	77.8	4.50
NM-5	25,140	57.6	8	82.6	2.25
NM-6	5,180	19.2	8	92.7	1.56
NM-7	55,440	71.6	8	60.6	2.93
NM-8	21,860	5.1	8	60.6	16.00
NM-9	25,390	64.0	8	87.1	2.16
NM-10	221,780	320	8	89.1	3.86
NM-11	113,710	192	15	82.3	1.62
MCM-1	175,690	89.6	33	68.9	2.05
MCM-2	220,100	110.2	34	72.7	2.13
MCM-3	71,000	570	33	58.5	0.11
MCM-4	137,830	211	33	68.5	0.68
MCM-6	120,310	580.4	38	81.0	0.23
MCM-7	105,770	173	37	71.5	0.59
MCM-8	642,370	224	36	79.4	3.16
MCM-9	154,350	509	31	69.4	0.34

NM = Navajo Mine
MCM = McKinley Mine

In general, sediment yields measured from the Navajo Mine basins were greater than those from the McKinley Mine basins. This observation has been attributed to the following factors:

- Average drainage area for the Navajo Mine basins (0.17 square miles) is less than the average drainage area for basins at the McKinley Mine (0.64 square miles);
- Drainage density is greater at the Navajo Mine basins (15.2 miles/square miles) than at the McKinley Mine basins (4.2 miles/square miles);
- The vegetation density is greater near the McKinley Mine basins (41 percent) than for basins near the Navajo Mine (15 percent); and
- The Navajo Mine basins have badland soil associations and none of the McKinley mine basins have badland soil associations.

The usefulness of this information for evaluation of background sediment yield is limited by several factors. First, the age of the the ponds was often uncertain and some may not have been in existence long enough to have received runoff and sediment resulting from large storm events that control watershed response in a semiarid environment. Second, reliable measurements of sediment yield can only be obtained if the ponds have not been breached or overtopped, and this information was not known. Third, ponds should be located in basins having geologic properties and morphometric (drainage area and density) properties similar to those of the mine watersheds. Some of the ponds near the McKinley mine did not meet this latter condition and exhibited low rates of sediment yield possibly due to the presence of geologic controls in channels and watersheds (i.e., exposed bedrock). Finally, sediment yield in the semiarid west is largely governed by the occurrence of localized, relatively large storm events. Without accurate data describing the rainfall conditions in the watershed, it is difficult to compute a meaningful average annual sediment yield. It is difficult to determine if the sediment yield is the result of a single, rare storm event (i.e., 50-year storm) or the result of a sequence of smaller events. Lacking accurate rainfall data, pond sediment volumes could not be used to directly calibrate a computer model.

5.5.2 Evaluation of Watershed Computer Models

The second objective of the study was to assess available watershed hydrologic and sediment transport models to determine the model most appropriate for use in evaluation of alternative sediment control practices. Detailed evaluations were made of five models (Water Engineering & Technology, 1990):

- ANSWERS - Areal Nonpoint Source Watershed Environmental Response Simulation
- KINEROS - Kinematic Erosion Model
- MULTSED - Watershed and Sediment Runoff Simulation Model for Multiple Watersheds
- PRMS - Precipitation-Runoff Modeling System
- SEDIMOT II/SEDCAD version - Hydrology and Sedimentology Watershed Model II

Each model was evaluated with respect to:

- Watershed representation;
- Rainfall components;
- Infiltration, interception and surface detention components;
- Runoff components;
- Sedimentation components;
- Ease of file generation;
- Performance with test data; and
- Sensitivity analysis of the various inputs and parameters.

Rather than developing an artificial data set to test the models, a data set obtained from the USDA-ARS Sedimentation Laboratory, Oxford Mississippi for a 4.7 acre, severely eroding soybean field in northwest Mississippi was used. These data include nine events that occurred during the 1985-1986 growing season and represent a wide range of vegetation cover. Two of the nine events were relatively extreme (both of approximate 10-year return periods, one having a duration of two hours and the other having a duration of four hours). Accurate measurements of rainfall, runoff and sediment yield were available for each event at this site, and the topography of the field was surveyed in great detail. Although this data set does not represent coal mines in a semiarid environment, the processes of infiltration, runoff generation, soil detachment, sediment transport and deposition can be considered universal.

Results of computer model tests are presented in Table 5p. Five models were ranked from one (most accurate) to five (least accurate) for seventeen categories. Twelve categories deal with physical processes. The other categories are (1) watershed representation, (2) generalization of watershed reproduction, (3) ease in subdividing watersheds and generating watershed data, (4) ease in generating other data files, and (5) performance of the model with test data.

Table 5p: Ranking of Five Computer Models

Category	ANSWERS	KINEROS	MULTSED	PRMS	SEDIMOT II
Rainfall	P 2	P 2	P 2	P 4	S 5
Interception	P 3	P 3	P 1	P 3	S 5
Infiltration					
Hillslope	E 4	P 2	P 2	P 2	S 5
Channel	N 4	P 2	P 1	N 4	N 4
Runoff					
Hillslope	P 2	P 1	P 4	P 3	S 5
Channel	P 2.5	P 2.5	P 2.5	P 2.5	P-S 5
Detachment					
Hillslope	P? 2.5	P? 2.5	P? 2.5	P? 2.5	S 5
Channel	N 3	P? 2	P? 1	N 4.5	N 4.5
Transport					
Hillslope	P? 1.5	P? 3	P? 1.5	P? 4	S 5
Channel	P? 1.5	P? 3	P? 1.5	P? 4.5	E 4.5
Deposition					
Hillslope	P? 1	P? 2	N 4	N 4	N 4
Channel	P? 1.5	P? 3	P? 1.5	N 5	E 5
Watershed Representation					
Generality	1.5	1.5	4	4	4
Generation	5	3	3	3	1
Performance with Test Data	3	1.5	1.5	(1 to 5)	4
Data File Generation	4	2	3	5	1
Areas of Concern	2	3	1	5	4
Sum of Ranks	**44**	**39**	**37**	**(60 to 65)**	**70**
Number of First Ranks	**8**	**7**	**12**	**3**	**2**

E = Empirical Relationship; N = Not Simulated; P = Process Based; P? = Process Assumption
1 = Highest Rank; 5 = Lowest Rank

As a result of these analyses, the MULTSED model achieved the most number of first place scores. Therefore, MULTSED was selected for use in subsequent phases of this project.

5.5.3 Rainfall Simulation Data Collection

Rainfall simulation testing was conducted at the Navajo Mine during 1987 and 1988 and at the McKinley Mine during 1988 to measure and collect data regarding the following parameters:

- Rainfall
- Runoff
- Sediment yield
- Soil properties
- Vegetation and cover densities

By testing paired plots (one plot to be used for model calibration and one to be used for model verification) and collecting data from two simulated rainstorms, four sets of data were obtained from each test site. Test sites encompassed a range of slopes, ages of reclamation and reclamation practices and included five test sites in undisturbed areas at each mine. The rainfall simulation testing program provided 76 data sets describing the rainfall-runoff-erosion process at the Navajo Mine (19 sites x 2 plots x 2 test runs) and 80 data sets at the McKinley Mine (20 sites x 2 plots x 2 test runs).

In addition, data were available for the Black Mesa Mine from 24 test plots (10-feet wide by 35-feet long) representing a range of slopes, surface treatments and watershed size (from 3 to 41 acres). Runoff and sediment yield generated by natural rainfall for Navajo Mine and McKinley Mine test plots and Black Mesa Mine watersheds were available for the period of 1983 to 1987. Tables 5q, 5r, and 5s contain a summary of the runoff and sediment yield information obtained from the Navajo, McKinley, and Black Mesa Mines, respectively.

Table 5q: Rainfall, Runoff and Sediment Yield Data for Navajo Mine

Plot	Storm Event Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
1	1	Right	2.5	1.42	27.0	8,690
	1	Left	2.2	0.72	6.7	4,240
	2	Right	2.6	2.02	36.8	8,320
	2	Left	2.6	2.08	33.0	7,260
2	1	Right	2.0	0.91	16.3	8,180
	1	Left	2.0	1.23	18.0	6,690
	2	Right	2.7	1.66	41.2	11,400
	2	Left	2.6	1.76	34.9	9,070
3	1	Right	2.0	0.75	10.1	6,210
	1	Left	2.7	0.85	13.0	6,970
	2	Right	2.1	1.31	32.4	11,300
	2	Left	2.4	1.31	30.0	10,500
4	1	Right	2.3	1.97	38.2	8,890
	1	Left	1.8	1.72	28.3	7,530
	2	Right	2.2	1.36	17.6	5,920
	2	Left	1.0	0.87	9.0	4,720
	3	Right	2.1	1.88	23.6	5,740
	3	Left	1.4	1.06	10.6	4,600
5	1	Right	2.0	0.28	0.8	1,310
	1	Left	2.3	0.71	1.4	922
	2	Right	2.7	0.90	6.1	3,110
	2	Left	2.2	0.98	5.4	2,530
6	1	Right	2.9	0.40	0.0	35
	1	Left	2.7	0.33	0.6	849
	2	Right	2.8	1.10	1.8	727
	2	Left	2.6	1.18	5.0	1,920
	3	Right	NDC	NDC	-	-
	3	Left	2.4	1.32	2.2	759
	4	Right	NDC	NDC	-	-
	4	Left	1.4	1.05	1.5	636

Plot	Storm Event Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
7	1	Right	2.3	0.50	0.3	283
	1	Left	2.2	0.81	0.4	238
	2	Right	2.6	0.68	0.6	281
	2	Left	2.3	1.14	0.6	224
8	1	Right	3.1	0.27	0.3	501
	1	Left	2.0	0.32	0.2	359
	2	Right	2.7	0.14	0.1	434
	2	Left	2.7	0.14	0.1	416
	3	Right	2.2	0.42	0.4	471
	3	Left	1.8	0.42	0.4	404
9	1	Right	2.3	1.32	209.0	72,500
	1	Left	2.7	0.53	244.8	73,200
	2	Right	2.4	2.26	341.1	68,900
	2	Left	2.2	1.89	240.8	58,300
10	1	Right	2.6	1.24	4.8	1,790
	1	Left	2.7	1.20	4.0	1,550
	2	Right	2.1	1.62	7.5	2,130
	2	Left	2.3	1.50	7.6	2,320
11	1	Right	2.3	1.12	6.9	2,800
	1	Left	2.2	1.02	11.5	5,160
	2	Right	2.4	1.68	22.5	6,150
	2	Left	2.0	1.29	19.2	6,800
12	1	Right	2.2	1.32	209.2	72,200
	1	Left	2.2	1.26	176.2	64,100
	2	Right	2.5	2.07	314.7	69,600
	2	Left	2.3	1.94	306.1	72,200
13	1	Right	2.4	0.00	0.0	0
	1	Left	2.2	0.00	0.0	0
	2	Right	2.7	0.41	0.8	866
	2	Left	2.4	0.44	1.0	1,050
14	1	Right	2.3	0.36	1.2	1,490
	1	Left	2.4	0.17	0.4	996
	2	Right	2.2	1.66	11.8	3,240

Plot	Storm Event Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
14	2	Left	2.6	1.58	9.6	2,790
15	1	Right	2.6	0.00	0.0	0
	1	Left	2.6	0.20	0.4	809
	2	Right	2.5	0.70	1.4	945
	2	Left	2.6	1.50	7.2	2,200
16	1	Right	2.5	0.55	1.6	1,380
	1	Left	2.6	0.47	2.2	2,100
	2	Right	2.9	2.51	5.5	1,010
	2	Left	2.9	2.56	6.1	1,080
17	1	Right	2.4	2.03	107.6	24,200
	1	Left	2.4	1.97	98.9	23,000
	2	Right	2.8	2.50	106.3	19,400
	2	Left	2.8	2.69	136.4	23,200
18	1	Right	2.3	0.63	0.8	569
	1	Left	2.0	0.28	0.2	396
	2	Right	2.5	1.24	2.3	849
	2	Left	2.5	1.30	1.4	496
19	1	Right	2.6	2.33	38.3	7,530
	1	Left	2.3	1.98	35.3	8,150
	2	Right	3.1	2.92	46.5	7,280
	2	Left	2.5	1.90	36.0	209.0

Table 5r: Rainfall, Runoff and Sediment Yield Data for McKinley Mine

Plot	Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
1	1	Right	1.9	0.09	0.6	3,150
	1	Left	2.8	0.98	6.2	2,880
	2	Right	3.0	0.81	6.3	3,550
	2	Left	2.4	1.05	6.0	2,630
2	1	Right	1.9	0.09	0.1	689
	1	Left	1.8	0.06	0.1	735
	2	Right	2.7	0.62	2.4	1,400
	2	Left	2.6	0.41	3.7	3,350
3	1	Right	2.8	0.74	4.1	2,520
	1	Left	2.1	0.61	18.8	14,000
	2	Right	3.0	1.43	8.2	2,610
	2	Left	1.8	0.77	4.6	2,750
4	1	Right	2.5	1.02	6.2	2,800
	1	Left	3.4	1.32	7.3	2,530
	2	Right	2.6	1.63	6.7	1,880
	2	Left	3.0	1.68	5.9	1,590
5	1	Right	3.6	1.40	15.1	4,940
	1	Left	3.2	0.87	13.8	7,240
	2	Right	3.1	1.74	14.6	3,830
	2	Left	2.9	1.09	12.2	5,100
6	1	Right	2.5	0.82	4.8	2,680
	1	Left	3.0	1.46	8.6	2,690
	2	Right	3.1	1.45	7.0	2,210
	2	Left	3.0	1.71	10.5	2,820
7	1	Right	3.1	0.53	0.5	322
	1	Left	2.9	0.012	0.04	1,530
	2	Right	2.4	0.98	0.5	184
	2	Left	3.3	1.28	2.8	923
8	1	Right	2.7	1.02	3.8	1,710
	1	Left	2.8	0.94	2.8	1,340

Plot	Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
8	2	Right	3.1	1.81	7.3	1,840
	2	Left	2.9	1.86	7.8	1,910
9	1	Right	2.3	0.46	1.9	1,910
	1	Left	3.1	0.81	8.2	4,640
	2	Right	2.8	1.13	8.4	3,420
	2	Left	2.9	1.02	12.6	5,650
10	1	Right	3.2	0.42	5.6	6,180
	1	Left	2.9	0.17	0.6	1,650
	2	Right	2.6	1.04	9.3	4,100
	2	Left	2.2	0.45	3.3	3.340
11	1	Right	3.1	0.89	19.5	10,010
	1	Left	3.4	1.44	39.1	12,470
	2	Right	3.2	2.05	44.2	9,850
	2	Left	2.5	1.66	31.2	8.580
12	1	Right	2.9	1.67	21.5	5,900
	1	Left	3.0	1.88	17.1	4,170
	2	Right	1.9	1.28	10.9	3,920
	2	Left	2.4	2.21	14.1	2,920
13	1	Right	2.3	0.74	12.0	7,430
	1	Left	3.1	0.98	32.3	15,050
	2	Right	2.5	1.27	19.4	6,980
	2	Left	2.6	1.41	31.5	10,230
14	1	Right	2.6	1.48	7.0	2,150
	1	Left	2.3	1.22	5.4	2,000
	2	Right	2.5	1.47	6.5	2,040
	2	Left	2.7	1.75	8.6	2,260
15	1	Right	2.4	1.65	7.1	1,960
	1	Left	2.5	1.46	8.3	2,610
	2	Right	2.3	2.00	9.3	2,120
	2	Left	3.1	2.19	10.9	2,280
16	1	Right	2.6	2.38	153.7	29,500
	1	Left	2.4	1.98	115.7	26,780

Plot	Run	SubPlot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
16	2	Right	2.4	1.89	100.5	24,290
	2	Left	2.2	1.83	81.3	20,350
17	1	Right	3.0	0.35	4.8	6,330
	1	Left	2.8	0.55	9.6	7,960
	2	Right	3.0	0.90	6.0	3,070
	2	Left	3.4	1.09	13.3	5,550
18	1	Right	2.3	0.80	11.7	6,730
	1	Left	3.1	1.10	40.5	16,890
	2	Right	3.1	1.78	53.6	13,760
	2	Left	2.5	1.42	42.1	13,550
19	1	Right	2.7	0.99	3.0	1,320
	1	Left	2.7	0.57	2.0	1,420
	2	Right	2.7	1.90	4.9	1,130
	2	Left	3.3	1.90	4.8	1,050
20	1	Right	2.4	1.54	86.5	25,710
	1	Left	2.6	1.62	95.8	27,070
	2	Right	2.7	2.19	93.4	19,510
	2	Left	2.8	2.27	100.0	20,160

Table 5s: Rainfall, Runoff and Sediment Yield Data for Black Mesa and Kayenta Mines

Watershed	Run Date	Plot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
N2 Small	7-21-86	221	0.9	0.012	0.190	8,710
	8-31-86		0.5	0.162	4.391	14,900
	9-23-86		0.9	0.057	0.208	1,990
	7-30-87		0.6	0.195	1.709	4,810
	8-31-86	222	0.5	0.256	8.077	17,300
	9-23-86		0.9	0.103	1.172	6,260
	7-30-87		0.6	0.147	4.049	15,100
	7-21-86	223	0.9	0.005	0.012	1,360
	8-31-86		0.5	0.116	1.849	8,720
	7-30-87		0.6	0.067	0.282	2,330
	7-21-86	224	0.9	0.005	0.010	1,120
	8-31-86		0.5	0.094	0.796	4,630
	9-23-86		0.9	0.024	0.042	960
	7-30-87		0.6	0.068	0.275	2,230
N2 Large	8-31-86	225	0.5	0.161	3.049	10,400
	9-23-86		0.9	0.138	0.250	991
	8-31-86	226	0.5	0.184	4.538	13,500
	9-23-86		0.9	0.149	0.377	1,390
	7-30-87		0.6	0.219	1.418	3,560
J27	8-31-85	271	0.5	0.004	0.004	500
	9-11-85		0.3	0.010	0.002	107
	7-20-86		0.5	0.006	0.003	288
	9-23-86		1	0.010	0.003	156
	8-31-85	272	0.5	0.006	0.015	1,440
	9-11-85		0.3	0.010	0.008	442
	7-20-86		0.4	0.007	0.011	893
	9-23-86		1	0.010	0.067	3,720
	8-31-85	273	0.5	0.027	0.098	1,970
	9-11-85		0.3	0.007	0.010	876
	7-20-86		0.5	0.005	0.009	886

Watershed	Run Date	Plot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
J27 (cont.)	9-23-86		1	0.078	0.167	1,180
	8-31-85	274	0.5	0.008	0.013	984
	9-11-85		0.3	0.005	0.002	242
	9-23-86		1	0.049	0.089	997
	8-31-85	275	0.5	0.037	0.087	1,310
	8-31-85	276	0.5	0.017	0.026	848
	9-11-85		0.3	0.003	0.000	0
	9-23-86		1	0.047	0.095	1,110
J3	7-29-85	303	1	0.307	7.802	13,900
	9-11-85		0.6	0.100	0.455	2,490
	9-18-85		0.5	0.026	0.132	2,770
	8-29-86		0.2	0.015	0.155	5,850
	9-08-86		0.3	0.017	0.198	6,270
	8-08-87		0.9	0.030	0.390	7,130
	7-29-85	304	1	0.436	10.538	13,300
	9-11-85		0.6	0.118	0.512	2,390
	9-18-85		0.5	0.085	0.143	927
	8-29-86		0.2	0.015	0.153	5,650
	9-08-86		0.3	0.033	0.315	5,270
	8-08-87		0.9	0.102	1.160	6,230
	7-29-85	305	1	0.436	16.936	21,300
	9-11-85		0.6	0.176	1.529	4,760
	9-18-85		0.5	0.133	0.400	1,650
	8-29-86		0.2	0.048	0.847	9,730
	9-08-86		0.3	0.089	1.508	9,280
	8-08-87		0.9	0.176	4.009	12,500
	7-29-85	306	1	0.257	3.354	7,170
	9-11-85		0.6	0.024	0.098	2,270
	9-18-85		0.5	0.023	0.067	1,620
	8-29-86		0.2	0.026	0.318	6,700
	9-08-86		0.3	0.028	0.144	2,810
	8-08-87		0.9	0.101	0.861	4,690
	7-29-85	307	1	0.163	3.755	12,700

Watershed	Run Date	Plot ID	Total Rainfall (in)	Total Runoff (in)	Total Sediment Yield (lbs)	Average Sediment Concentration (ppm)
J3 (cont.)	9-11-85		0.6	0.084	0.397	2,600
	9-18-85		0.5	0.024	0.067	1,530
	8-29-86		0.2	0.006	0.019	1,900
	7-29-85	308	1	0.180	4.953	15,100
	9-11-85		0.6	0.080	0.879	6,020
	9-18-85		0.5	0.024	0.163	3,760
	8-08-87		0.9	0.028	1.097	21,300
N6	9-18-85	261	0.4	0.023	0.407	9,510
	9-23-86		0.8	0.074	0.445	3,290
	9-18-85	262	0.4	0.018	0.060	1,820
	9-23-86		0.8	0.072	0.330	2,540
	9-18-85	263	0.4	0.003	0.006	1,190
	7-21-86		0.6	0.012	0.037	1,670
	9-08-86		0.9	0.191	1.200	3,450
	9-23-86		0.8	0.090	0.144	884
	9-18-85	264	0.4	0.017	0.034	1,090
	7-21-86		0.6	0.017	0.060	1,900
	9-08-86		0.9	0.106	1.219	6,310
	9-23-86		0.8	0.115	0.750	3,570
	9-18-85	265	0.4	0.006	0.012	1,130
	7-20-86		0.5	0.005	0.032	3,880
	7-21-86		0.6	0.028	0.218	4,200
	9-23-86		0.8	0.045	0.132	1,610
	9-18-85	266	0.4	0.010	0.018	993
	7-20-86		0.5	0.005	0.019	1,980
	7-21-86		0.6	0.018	0.135	4,110
	9-23-86		2.5	0.039	0.103	1,440

5.5.4 Calibration and Validation of the MULTSED Model

The first step in the application of MULTSED for prediction of runoff and sediment yield involved calibration and validation of the model using the data collected from the Navajo, McKinley, and Black Mesa/Kayenta mines. One-half of the simulated rainfall test plot data were used for calibration and determination of appropriate infiltration and soil detachment coefficients. Following calibration, the MULTSED model was run using the calibrated infiltration and detachment coefficients to predict sediment yield and mean sediment concentration. Finally, total runoff, sediment yield, and mean sediment concentration predicted by MULTSED were compared to the remaining half of the simulated rainfall test plot data and to the available Black Mesa/Kayenta Mine data. Model verification determined that runoff amounts were predicted with the greatest accuracy, followed by mean concentration, and sediment yields.

Model results also showed a tendency for the model to over predict sediment. Runoff rates for low flow conditions should not be of major concern, because long-term erosion rates generally are dominated by extreme conditions when large magnitude runoff volumes occur. However, when predicting the runoff and sediment responses of various erosion control alternatives, the model should not be used for small storms that produce small amounts of runoff (< 0.5 inches).

5.5.5 Evaluation of Alternative Sediment Control Techniques

Successful calibration and validation of the MULTSED model provided a means to evaluate the effectiveness of alternative sediment control techniques relative to background conditions. To make these comparisons, a procedure was developed that uses rainfall depth-duration information available from National Oceanic and Atmospheric Administration (NOAA) Atlases at each mine site. Rainfall data describing storm events with recurrence intervals of 2, 5, 10, 25, 50, and 100 years were used to develop hypothetical storm distributions. MULTSED was then used to determine the runoff and sediment generated from a hill slope for this range of storm events.

Comparisons were made between background sediment yield and predicted sediment yields associated with alternative sediment control techniques. Average annual sediment yield was computed using a probability weighting procedure that uses an incremental probability of occurrence of the aforementioned sequence of storms. Since the average value computed using this procedure is based on a broad range of storm events, it is expected to represent a reasonable long-term average. It should be noted that, depending on the sequence of storm events that actually occur, sediment yield within any given year could significantly deviate from this average value. For purposes of comparison, however, this calculation procedure provides a reasonable value for sediment yield.

Modeling was performed to evaluate sediment yield response to variations in slope length, slope gradient, cover density, and the presence or absence of furrows (depression storage) on the reclaimed surface. The results agreed with expectations: sediment yield increases with increasing plot slope gradient and slope length, decreases with increasing vegetative cover, and decreases with increased depression storage. Model prediction results for the sediment yield response to ASCs at the Navajo Mine, McKinley Mine, and Black Mesa/Kayenta Mine are presented in Figures 5d through 5q.

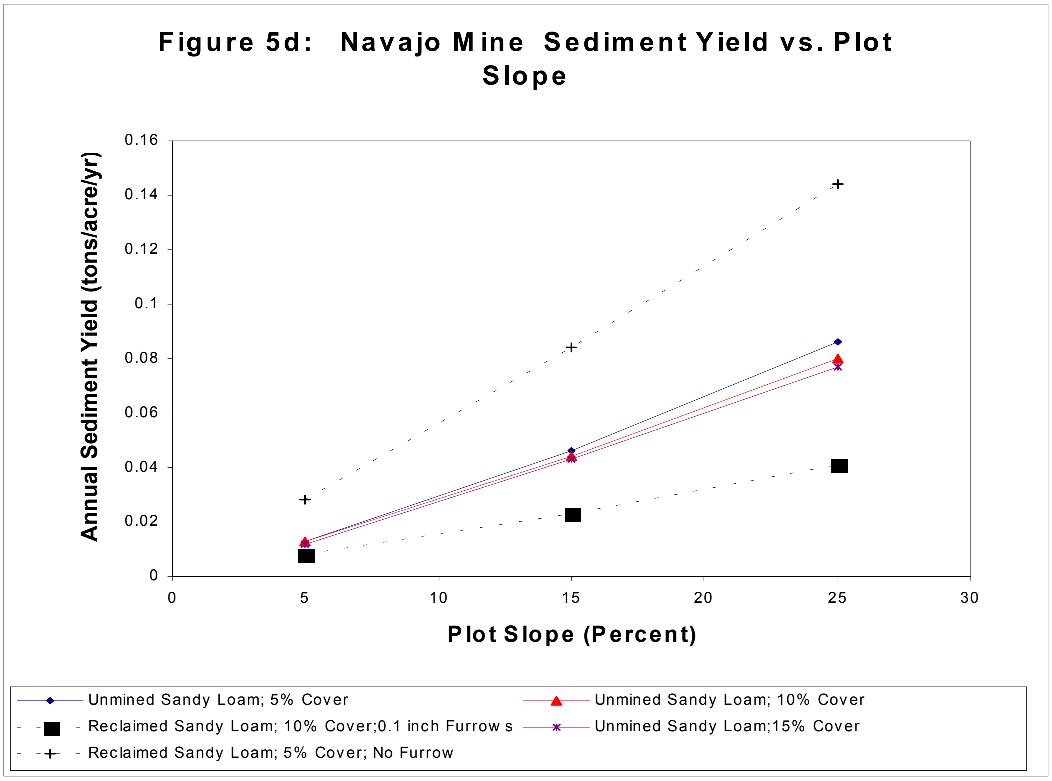


Figure 5d: Navajo Mine Sediment Yield vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
Plot Slope (Percent)
Unmined Sandy Loam; 5% Cover
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover;0.1 inch Furrow s
Unmined Sandy Loam;15% Cover
Reclaimed Sandy Loam; 5% Cover; No Furrow

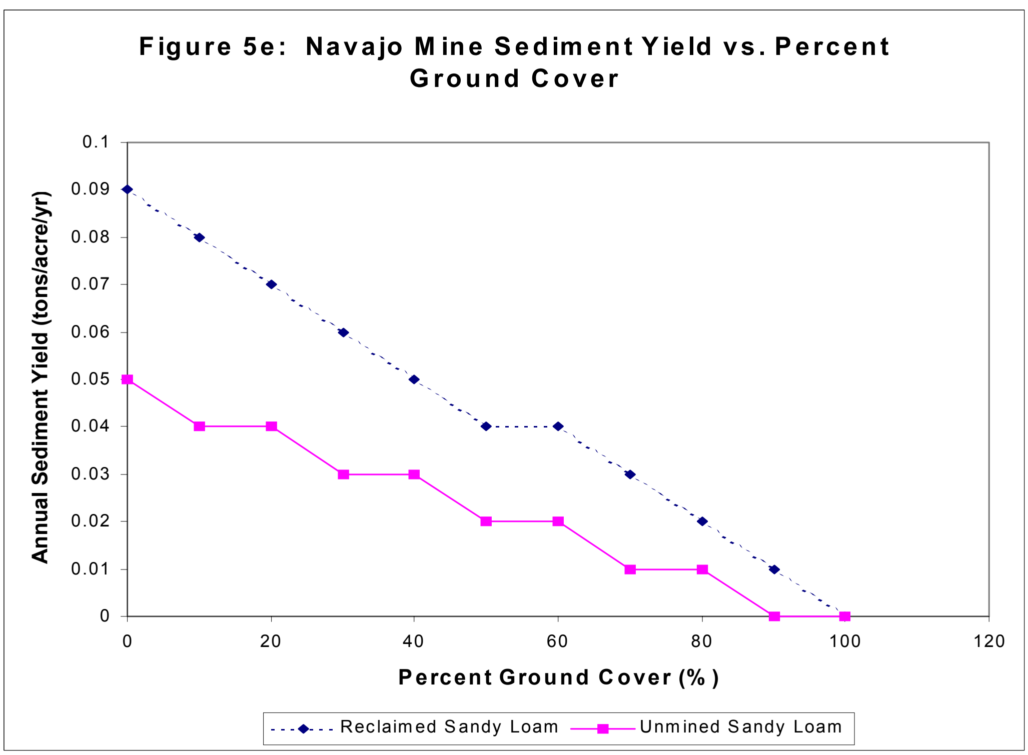


Figure 5e: Navajo Mine Sediment Yield vs. Percent Ground Cover
Annual Sediment Yield (tons/acre/yr)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
100
120
Percent Ground Cover (%)
Reclaimed Sandy Loam
Unmined Sandy Loam

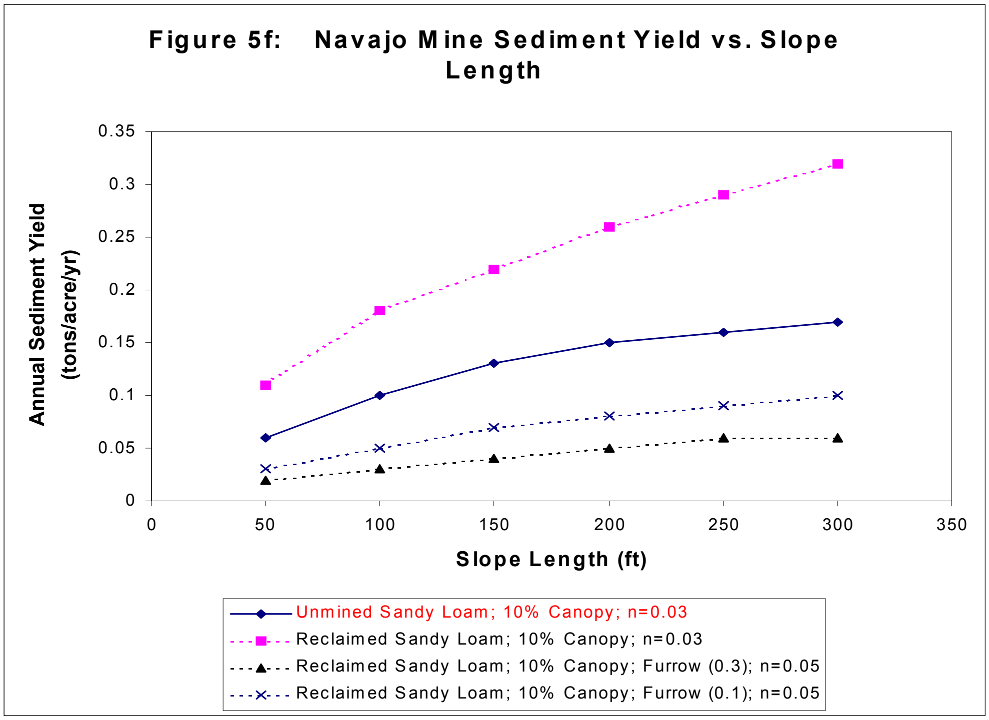


Figure 5f: Navajo Mine Sediment Yield vs. Slope Length
Annual Sediment Yield (tons/acre/yr)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Sandy Loam; 10% Canopy; n=0.03
Reclaimed Sandy Loam; 10% Canopy; n=0.03
Reclaimed Sandy Loam; 10% Canopy; Furrow (0.3); n=0.05
Reclaimed Sandy Loam; 10% Canopy; Furrow (0.1); n=0.05

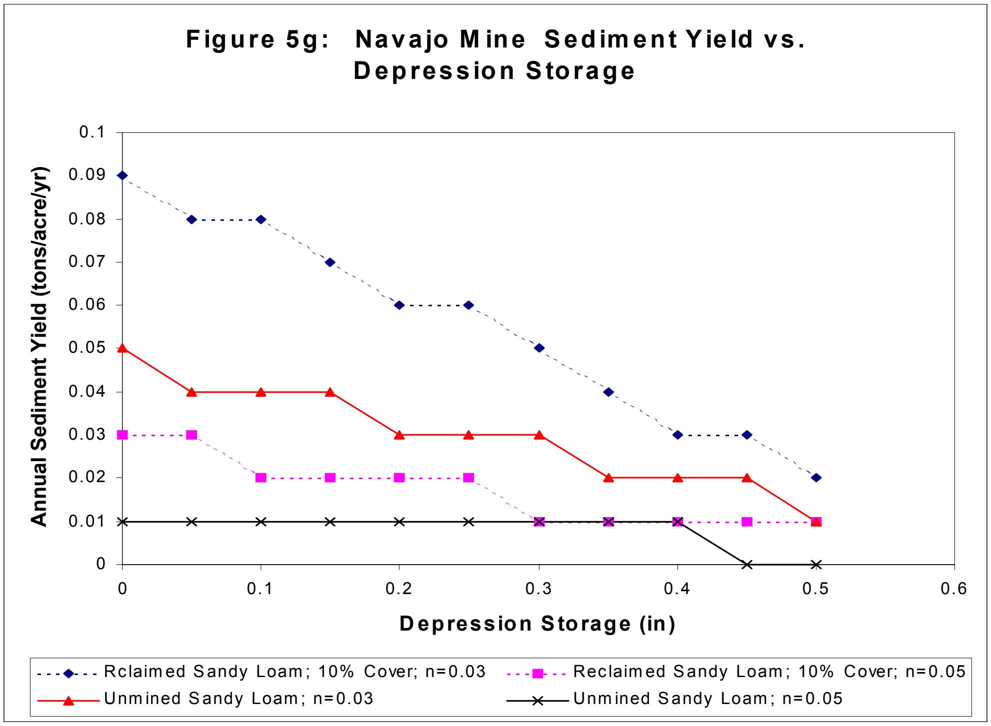


Figure 5g: Navajo Mine Sediment Yield vs. Depression Storage
Annual Sediment Yield (tons/acre/yr)
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
0.1
0.2
0.3
0.4
0.5
0.6
Depression Storage (in)
Rclaimed Sandy Loam; 10% Cover; n=0.03
Reclaimed Sandy Loam; 10% Cover; n=0.05
Unmined Sandy Loam; n=0.03
Unmined Sandy Loam; n=0.05

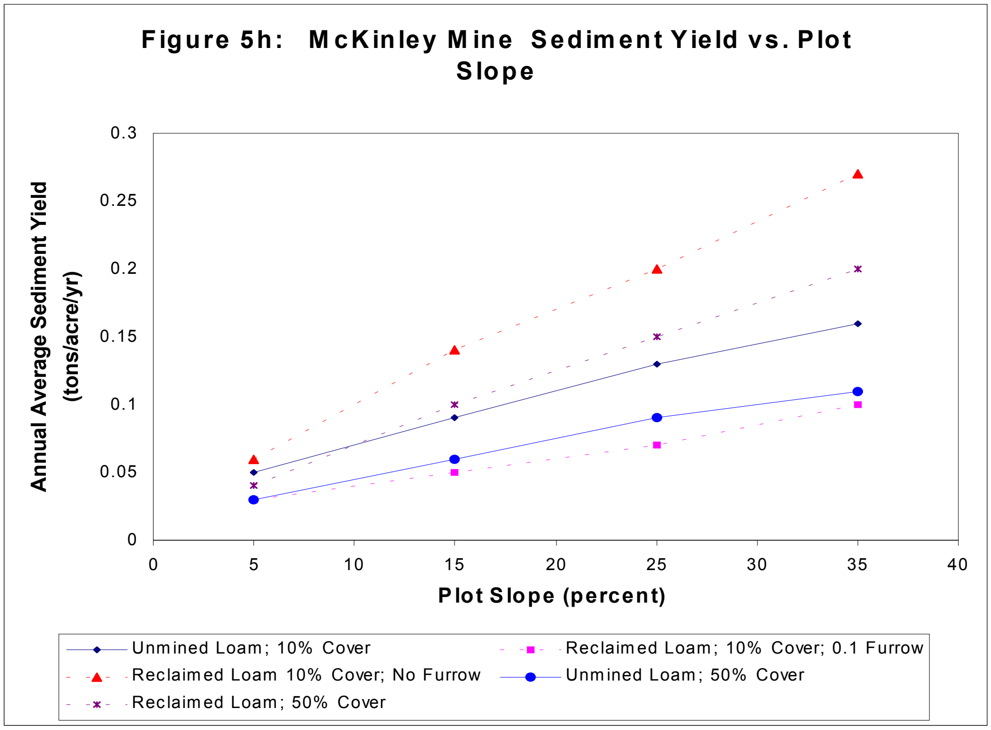


Figure 5h: McKinley Mine Sediment Yield vs. Plot Slope
Annual Average Sediment Yield (tons/acre/yr)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
5
10
15
20
25
30
35
40
Plot Slope (percent)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 Furrow
Reclaimed Loam 10% Cover; No Furrow
Unmined Loam; 50% Cover
Reclaimed Loam; 50% Cover

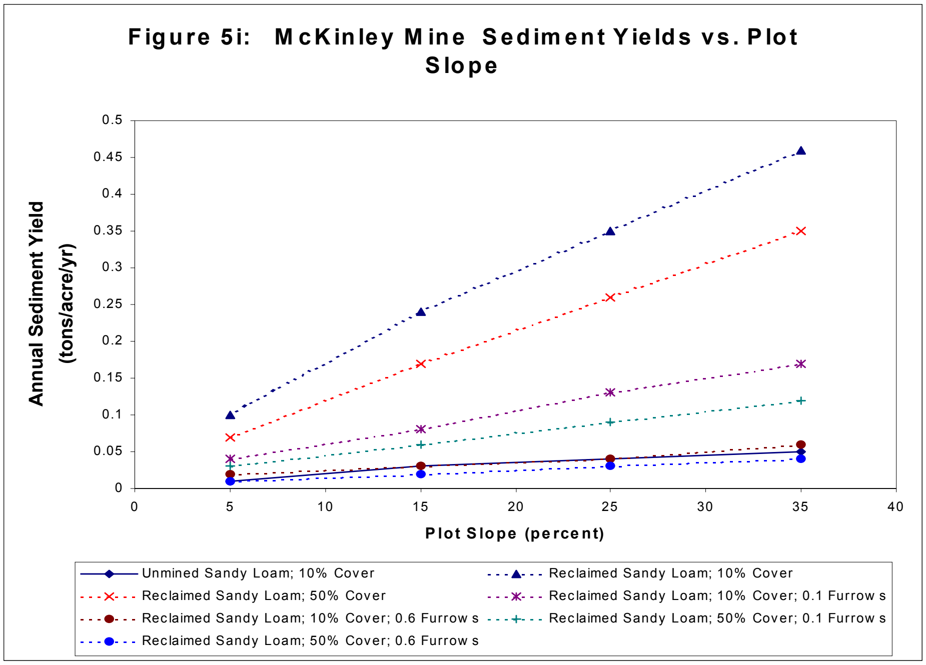


Figure 5i: McKinley Mine Sediment Yields vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
5
10
15
20
25
30
35
40
Plot Slope (percent)
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 50% Cover
Reclaimed Sandy Loam; 10% Cover; 0.1 Furrows
Reclaimed Sandy Loam; 10% Cover; 0.6 Furrows
Reclaimed Sandy Loam; 50% Cover; 0.1 Furrows
Reclaimed Sandy Loam; 50% Cover; 0.6 Furrows

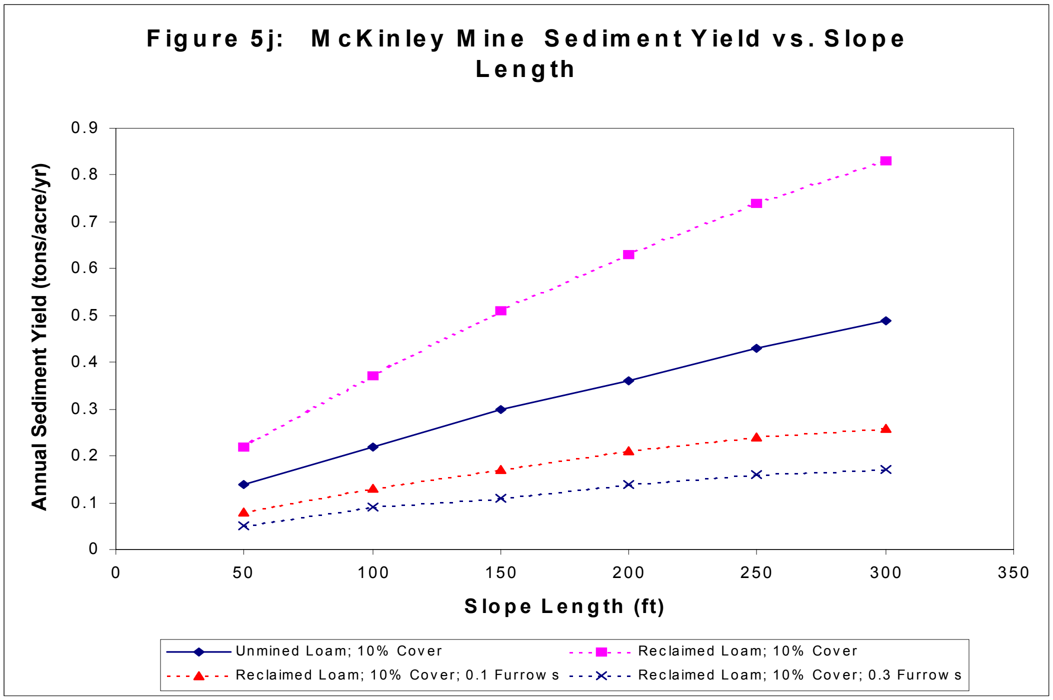


Figure 5j: McKinley Mine Sediment Yield vs. Slope Length
Annual Sediment Yield (tons/acre/yr)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 Furrow s
Reclaimed Loam; 10% Cover; 0.3 Furrow s

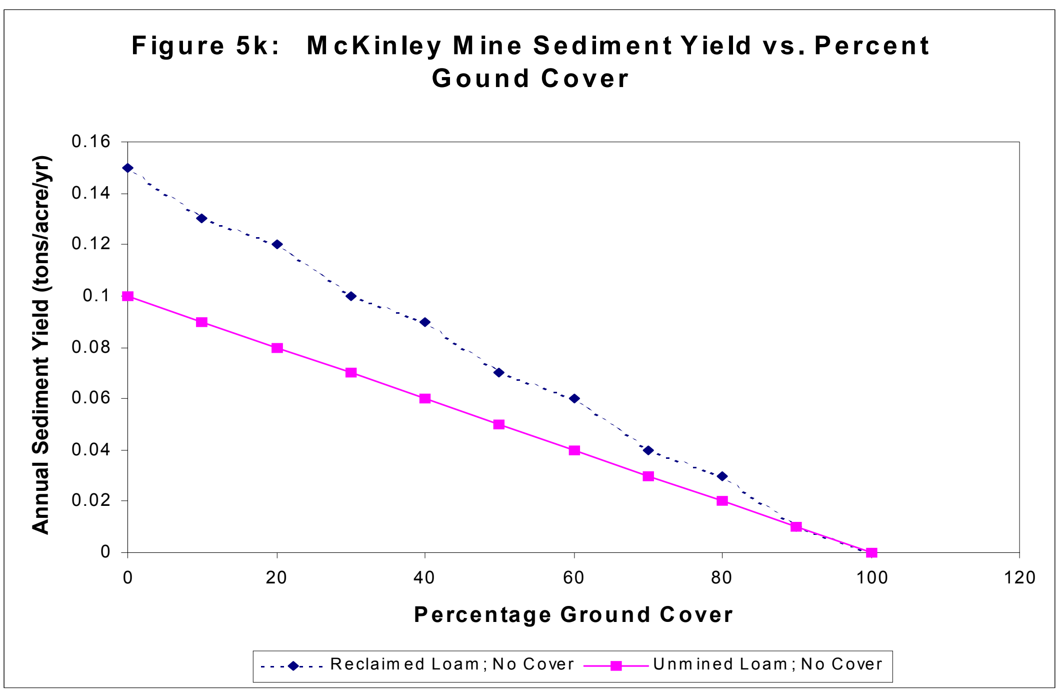


Figure 5k: McKinley Mine Sediment Yield vs. Percent Gound Cover
Annual Sediment Yield (tons/acre/yr)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
120
Percentage Ground Cover
Reclaimed Loam; No Cover
Unmined Loam; No Cover

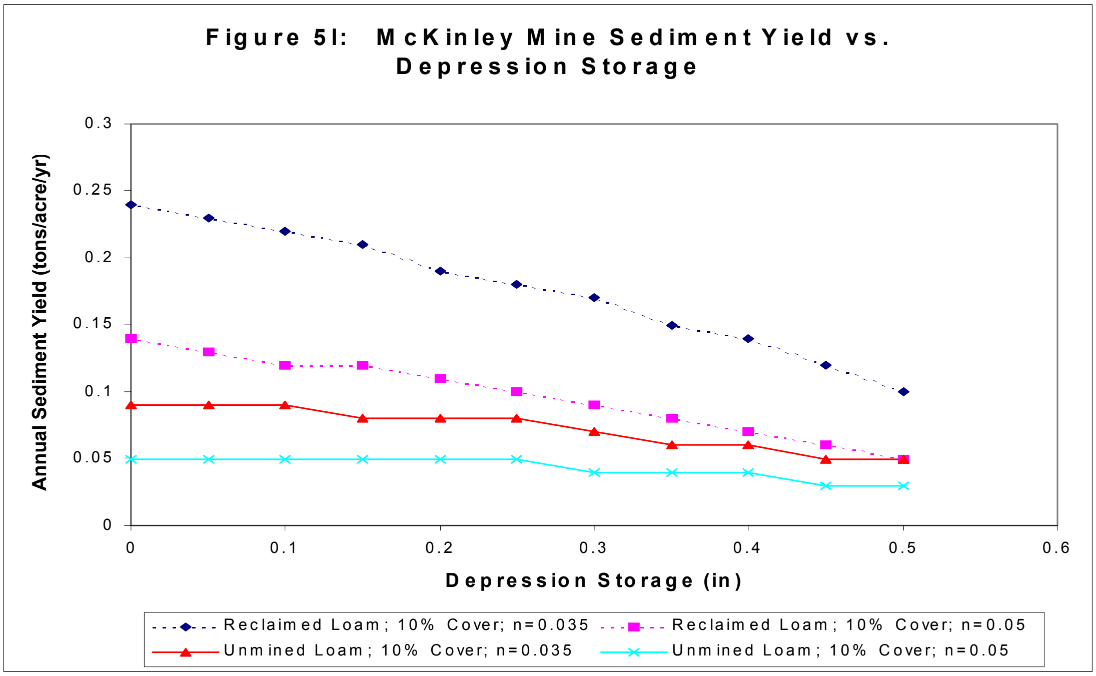


Figure 5l: McKinley Mine Sediment Yield vs. Depression Storage
Annual Sediment Yield (tons/acre/yr)
0
0.05
0.1
0.15
0.2
0.25
0.3
0
0.1
0.2
0.3
0.4
0.5
0.6
Depression Storage (in)
Reclaimed Loam; 10% Cover; n=0.035
Reclaimed Loam; 10% Cover; n=0.05
Unmined Loam; 10% Cover; n=0.035
Unmined Loam; 10% Cover; n=0.05

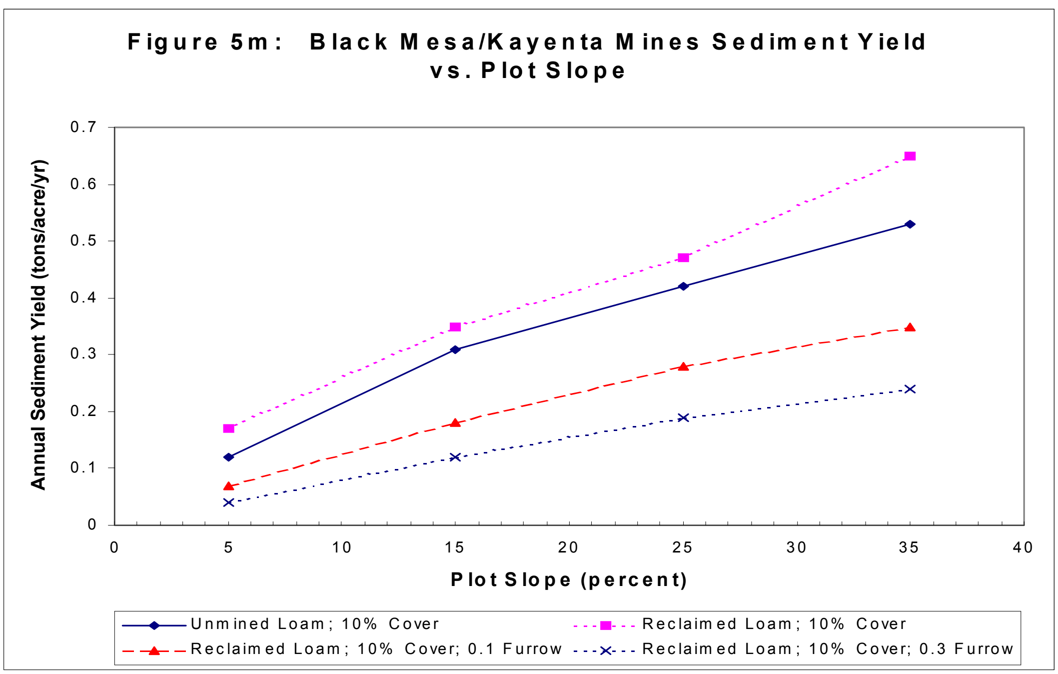


Figure 5m: Black Mesa/Kayenta Mines Sediment Yield vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
5
10
15
20
25
30
35
40
Plot Slope (percent)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 Furrow
Reclaimed Loam; 10% Cover; 0.3 Furrow

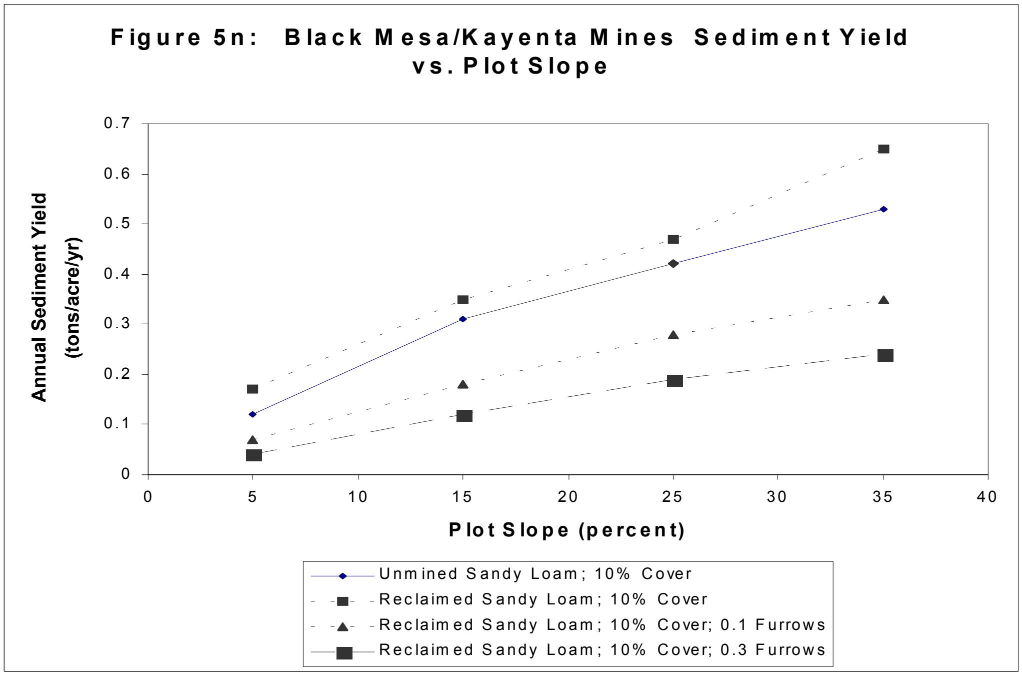


Figure 5n: Black Mesa/Kayenta Mines Sediment Yield vs. Plot Slope
Annual Sediment Yield (tons/acre/yr)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
Plot Slope (percent)
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover; 0.1 Furrows
Reclaimed Sandy Loam; 10% Cover; 0.3 Furrows

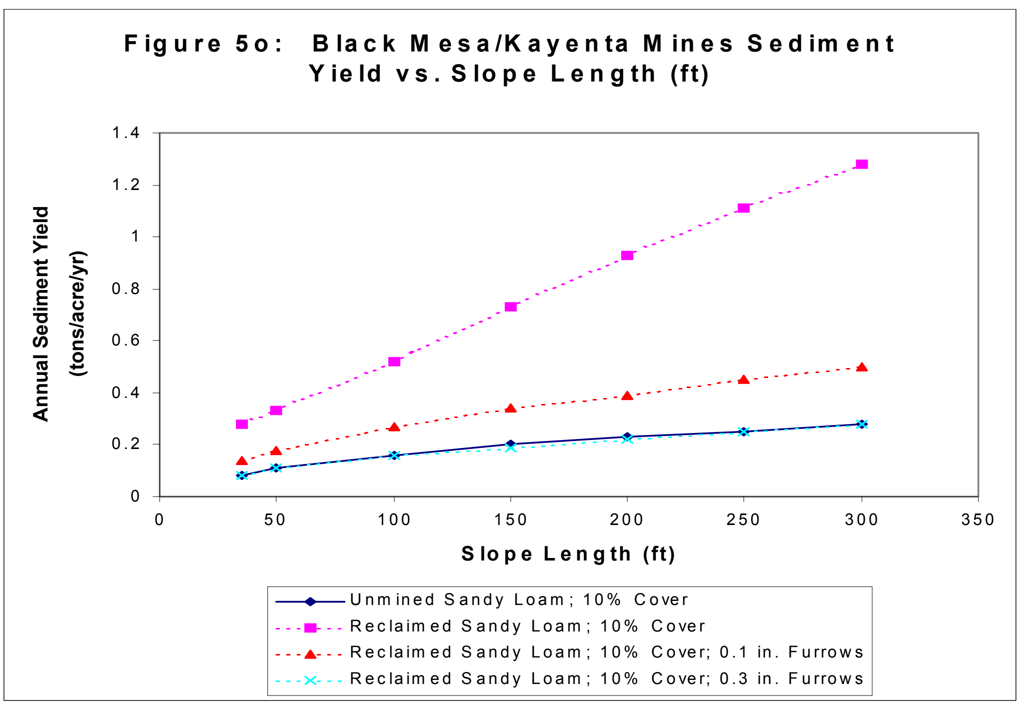


Figure 5o: Black Mesa/Kayenta Mines Sediment Yield vs. Slope Length (ft)
Annual Sediment Yield (tons/acre/yr)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover
Reclaimed Sandy Loam; 10% Cover; 0.1 in. Furrows
Reclaimed Sandy Loam; 10% Cover; 0.3 in. Furrows

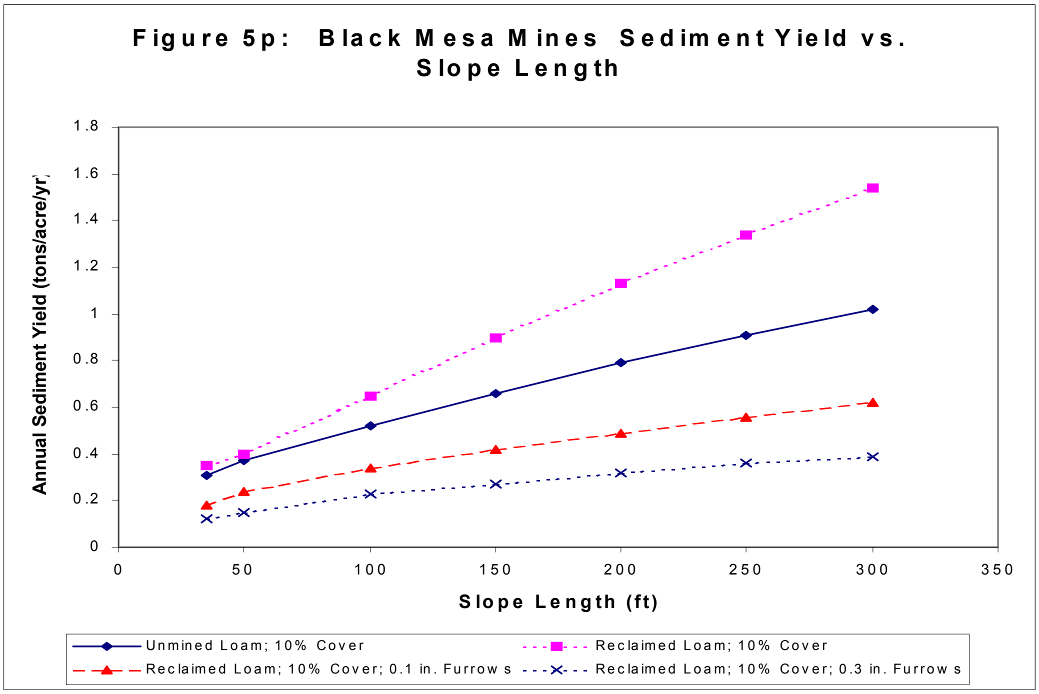


Figure 5p: Black Mesa Mines Sediment Yield vs. Slope Length
Annual Sediment Yield (tons/acre/yr)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
Slope Length (ft)
Unmined Loam; 10% Cover
Reclaimed Loam; 10% Cover
Reclaimed Loam; 10% Cover; 0.1 in. Furrows
Reclaimed Loam; 10% Cover; 0.3 in. Furrows

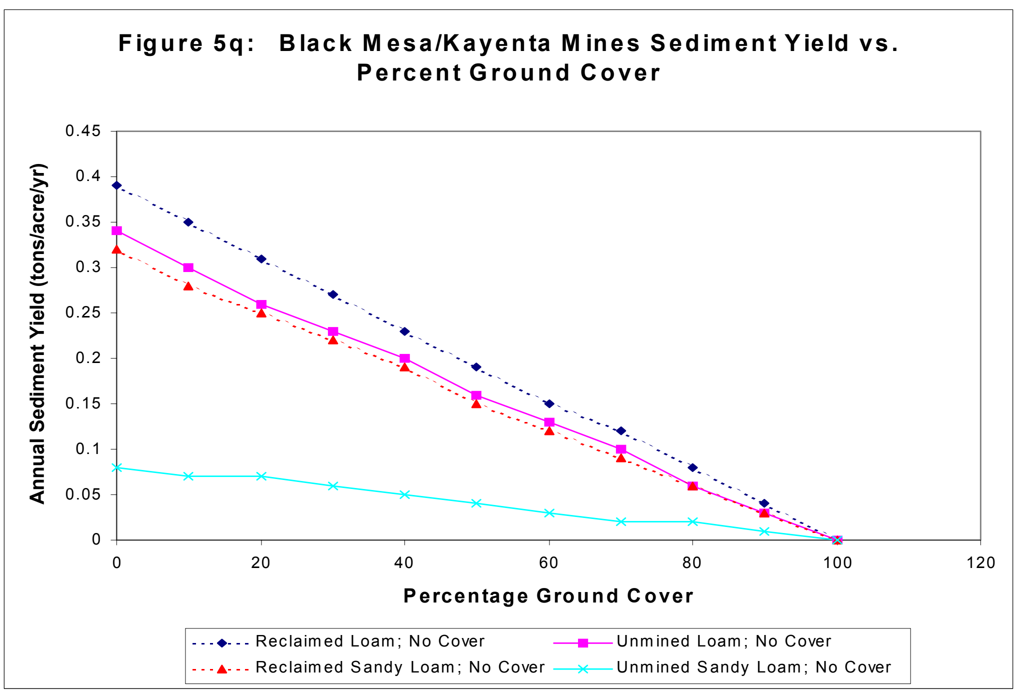


Figure 5q: Black Mesa/Kayenta Mines Sediment Yield vs. Percent Ground Cover
Annual Sediment Yield (tons/acre/yr)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
Percentage Ground Cover
Reclaimed Loam; No Cover
Unmined Loam; No Cover
Reclaimed Sandy Loam; No Cover
Unmined Sandy Loam; No Cover

5.5.5.1 Navajo Mine

Model prediction results indicate that alternate sediment controls can be used to produce sediment yields that are less than background or unmined conditions. For example, an unmined sandy loam of 15 percent slope and 10 percent vegetative cover density produces more sediment than a reclaimed sandy loam of 25 percent slope and a 5 percent vegetative cover density if furrows capable of retaining 0.1 inch of rainfall are present and slope lengths are equal (Figure 5d). It is important to note that these furrows are only a temporary measure and a more permanent reclamation technique should be implemented. An example of this would be using rock or mulch as a ground cover.

Figure 5d also provides a comparison of pre-and post-mined sandy loams. The figure indicates that reclaimed sandy loams (post-mining) with vegetation (5 percent cover) but without furrows results in higher sediment yields than unmined areas of similar soil/sand cover for any slope. Figure 5d also indicates that achievement of background sediment yields solely through manipulation of slope gradient requires that the reclaimed slope gradient be significantly reduced. For example, to maintain a reclaimed sediment yield comparable to that of an unmined sandy loam on a 10 percent slope, the reclaimed slope not exceed 5 percent.

The effects of varying ground cover on sediment yield for sandy loams are shown in Figure 5e. A reclaimed sandy loam site would require significantly more ground cover to produce the same sediment yield as an unmined sandy loam site. For example, a reclaimed sandy loam soil with at least 60 percent ground cover would yield approximately the same amount of sediment as unmined sandy soil with 20 percent ground cover.

Figure 5f provides a comparison of sediment yields from pre- and post-mining sandy loam sites based on slope lengths. Based solely on slope length, reclaimed slope lengths should be less than 50 feet to maintain background sediments yields for an unmined sandy loam site with an original slope length of 100 feet.

Figure 5g illustrates the effectiveness of furrows in reducing hillslope sediment yield. Surfaces with furrows tend to be rougher and therefore have higher Manning n values than surfaces without furrows. For computer modeling purposes, plots without furrows were given a Manning n of 0.03 and plots with furrows were given values of 0.05.

5.5.5.2 McKinley Mine

Similar to the Navajo Mine computer prediction results, Figure 5h shows that a significant reduction in reclaimed slope gradient is required to maintain sediment yield below background levels. Figure 5h also shows that reclaimed loam soil with 10 percent canopy cover and furrows capable of retaining 0.1 inch of rainfall produces less sediment than an unmined loam soil with 50 percent canopy cover. Figure 5i indicates that reduction of slope gradient by itself would not be sufficient to reduce sediment yield below background levels with a sandy loam soil at the McKinley Mine. A reclaimed sandy loam soil with a 50 percent canopy cover and furrows capable of retaining 0.6 inches of rainfall will produce less sediment than an unmined sandy loam with 10 percent canopy cover.

The average annual sediment yield for reclaimed loam soils also was compared to background conditions for different slope lengths, percentages of ground cover and amounts of depression storage as shown in Figures 5j, 5k, and 5l. Figure 5j shows that a 300-foot long reclaimed loam soil plot, with furrows capable of holding 0.1 inches of rainfall, produces less sediment than an unmined 150-feet long loam soil plot. Figure 5k illustrates that a reclaimed loam soil with at least 60 percent ground cover will yield approximately as much sediment as an unmined loam soil with 40 percent ground cover. Figure 5l shows the effect of depression storage and roughness on annual sediment yield. Reclaimed soils are much more sensitive to the amount of depression storage than unmined soils. Also as can be seen from 5l, a loam soil can be temporarily reclaimed to meet the background sediment yield of an unmined loam soil with 0.1 inch of depression storage ($n = 0.035$).

5.5.5.3 Black Mesa/Kayenta Mines

Figures 5m and 5n show the sediment yield response of a loam soil and sandy loam soil to changes in slope gradient for both pre- and post-mining conditions, respectively. Both figures show that a modest 3 to 5 percent reduction in slope gradient can maintain sediment yields at or below background levels. Also shown in both figures are the effects of contour furrows on sediment yield. Figure 5m shows that reclaiming loam soil with furrows that are capable of retaining at least 0.1 inch of rainfall will satisfy the requirement of producing less sediment than the amount produced by background conditions. Reclaimed sandy loam soil requires furrows capable of retaining 0.5 inches of rainfall to meet the background criteria as shown in Figure 5n.

Figures 5o and 5p show the same results as Figures 5m and 5n, except that they include slope length instead of plot slope. Figure 5o shows that for sandy loam soils, decreasing the slope length of the reclaimed area and reclaiming with furrows may be necessary to meet background sediment yields.

As shown in Figure 5q, for reclamation of loam and sandy loam soils that originally had 20 percent ground cover with rock mulch, a 30 percent ground cover and a 80 percent ground cover would be necessary for the loam and sandy loam soils respectively.

5.5.5.4 Conclusions

Comparisons were made between the erosion potential of reclaimed land versus undisturbed hillslope surfaces. In general, results of this evaluation tend to indicate that erosion potential of reclaimed surfaces exceeds that of unmined lands, when all other conditions are held constant. The addition of contour furrows to the land surface tends to significantly reduce erosion potential, however such features generally last only a few years. Contour furrows can also tend to hinder seeding and revegetation efforts.

More permanent forms of alternative sediment control practices include:

- Manipulation of the slope gradient,
- Manipulation of slope length,
- Modification of the density of surface cover (vegetation, mulch, etc.),
- Alteration of the hillslope surface to increase roughness or depression storage, and
- Enhancement of infiltrative capacity of the soil.

Evaluation of the first four sediment control alternatives listed above shows that these alternatives generally can be used to meet the background performance standard. Depending on the specific properties of any particular site, defined by such variables as hillslope gradient and length, cover density, soil particle size distribution and infiltration capacity, one or more of these measures may be required for alternative sediment control to be effective. According to this study, the recommended procedure for evaluation of alternative sediment control requires use of the MULTSED model to define the background conditions of runoff and sediment yield for a range of storm conditions. Modeling of the reclaimed conditions then indicates the relative differences in runoff/erosion response resulting from mining activities. If post-mining erosion exceeds the undisturbed erosion potential, MULTSED can be applied to evaluate the necessary modifications to the watershed system to meet the background performance standard.